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A SERIES OF
CHEMICAL PROBLEMS

A SERIES OF

CHEMICAL PROBLEMS

With Key

FOR USE IN COLLEGES AND SCHOOLS

BY

Thomas Edward

T. E. THORPE, B.Sc. (Vict.), Ph.D. F.R.S.

REVISED AND ENLARGED BY

W. TATE, Assoc. N.S.S. (Honours), F.C.S.

WITH A PREFACE

BY SIR H. E. ROSCOE, B.A. Ph.D. F.R.S. M.P.

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PREFACE

THE following complete series of Questions and Problems in Elementary Chemistry will prove a great boon to those engaged either in teaching or in learning the science. They were prepared by my friend DR. THORPE, with special reference to our junior classes in Owens College, in which my "Elementary Chemistry" is used; but they will of course also be available where any other modern text-book is employed.

My experience has led me to feel more and more strongly that by no method can accuracy in a knowledge of Chemistry be more surely secured than by attention to the working of well-selected problems, and Dr. Thorpe's thorough acquaintance with the wants of the student is a sufficient guarantee that this selection has been carefully made. I intend largely to use these Questions in my own classes, and I can confidently recommend them to all teachers and students of the science.

HENRY E. ROSCOE.

Oct. 15, 1870.

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CHEMICAL CALCULATIONS.

METRIC SYSTEM OF WEIGHTS AND MEASURES.

MEASURES OF LENGTH.

Standard :—1 metre, the length at 0°C. of a platinum bar preserved in Paris. Originally constructed to represent the $\frac{1}{40000000}$ part of the earth's circumference, measured along the Paris meridian ; according to modern measurements it does not fulfil this intention and can therefore only be viewed as an empirical standard.

10 decimetres (dcm.) . . .	1 metre (m.).
100 centimetres (cm.) . . .	„
1000 millimetres (mm.) . . .	„
1000 metres	1 kilometre.

1 inch = 2·539954 centimetres.
1 foot = 3·047945 decimetres.
1 yard = 0·914383 metre.
1 mile = 1·609315 kilometres.

MEASURES OF SURFACE.

100 square decimetres (sq. dcm.)	1 square metre or centiare (sq. m.).
10,000 „ centimetres (sq. cm.)	„
1,000,000 „ millimetres (sq. mm.)	„
100 square metres	1 are.
10,000 „ „	1 hectare.

1 square inch = 6·4513669 sq. cm.
1 „ foot = 9·2899683 sq. dcm.
1 „ yard = 0·83609715 sq. m.
1 „ acre = 0·404671021 hectare.

MEASURES OF CAPACITY.

1000 cubic decimetres (c.dcm.)	1 cubic metre or stere.
1,000,000 „ centimetres (c.c.)	„
1,000,000,000 „ millimetres (c.mm.)	„
1 cubic decimetre . . .	1 litre.

1 cubic inch = 16·386176 c.c.
1 „ foot = 28·315312 c.dcm.
1 gallon = 4·54345797 litres.

MEASURES OF WEIGHT.

Standard :—1 kilogram, the mass of a piece of platinum weighed *in vacuo;* preserved in Paris.

Theoretically the gram equals the mass of 1 c.c. and the kilogram the mass of 1000 c.c. of distilled water at 4°C., at the latitude of Paris; the actual standard differs slightly from its value as thus defined.

1000 grams (grms.) . . .	1 kilogram
10,000 decigrams.	„
100,000 centigrams	„
1,000 000 milligrams	„

1 grain = 0·06479895 gram.
1 troy oz. = 31·103496 grms.
1 lb. avd. = 0·45359265 kilo.
1 cwt. = 50·80237689 kilos.

To reduce grams to grains.
Log. grams + 1·188432 = log. grains.

To reduce cubic centimetres to cubic inches.
Log. c.c. + (−2·7855224) = log. cubic inches.

To reduce millimetres to inches.
Log. mm. + (−2·5951742) = log. inches.

To convert grains into grams.
Log. grains + (−2·8115680) = log. grams.

To convert cubic inches into cubic centimetres.
Log. cb. in. + 1·2144776 = log. c.c.

To convert inches into millimetres.
Log. inches + 1·4048258 = log. mm.

SURFACES AND CAPACITIES.

Area of a square = side^2.

Area of a rectangle, rhombus, or rhomboid = side × perpendicular height.

Area of a triangle = half the side × perpendicular height.

Area of a circle = $3{\cdot}141593 \times \text{radius}^2$.

Area of an ellipse = 3·141593 × major semi-axis × minor semi-axis.

Surface of a cube = $6 \times \text{edge}^2$.

Surface of a sphere = $12{\cdot}566370 \times \text{radius}^2$.

Surface of a cylinder = 6·283185 × radius of base × sum of height and radius of base.

Surface of a spherical segment = 6·283185 × height × radius of circular base.

Volume of a cube = edge^3.

Volume of a sphere = $\frac{4}{3} \times 3{\cdot}141593 \times \text{radius}^3$.

Volume of a cylinder = $3{\cdot}141593 \times \text{height} \times \text{radius}^2$.

Volume of a prism = base area × height.

Volume of a cone or pyramid = $\frac{1}{3}$ × base area × height.

EXAMPLES.

1. How many millimetres are contained in 5 metres? From the table we find that 1000 millimetres = 1 metre.

∴ 5 metres = 1000 × 5, or 5000 millimetres.

2. How many decimetres are equivalent to 106725 millimetres?

1 decimetre = 100 millimetres.
∴ 106725 millimetres = 1067·25 decimetres.

3. How many litres of air are contained in a room measuring 4 × 3 × 2 metres?

4 × 3 × 2 = 24 cubic metres.
1 cubic metre = 1000 litres.
∴ 1000 × 24 = 24,000 litres.

4. Required the number of milligrams in 15 c.c. of water measured at 4° C.

1 c.c. of water at 4° C. = 1 gram.
1000 milligrams = 1 gram.
∴ 15 × 1000 = 15,000 milligrams.

QUESTIONS.

1. How many millimetres, centimetres, and decimetres are respectively contained in 0·437 of a decimetre?

2. Required the number of (*a*) centimetres, (*b*) decimetres, (*c*) metres, in 1098765421 millimetres.

3. Required the number of square millimetres, square centimetres, square decimetres contained in the top of a table measuring 1 metre by 70 centimetres.

4. Define the gram and the litre. How many grams are contained in 1·725 kilograms?

5. How many centigrams are contained in 2·567 kilograms?

6. Required the number of milligrams contained in 5 cubic centimetres of water measured at 4°C.

7. Calculate the number of square centimetres contained on the surface of a paper filter possessing a radius of 5 centimetres.

8. In an English inch are contained 25·3995 millimetres. How many kilometres are there in a mile?

9. The mean height of the barometer in the latitude of Greenwich at the level of the sea is 30 inches. How many millimetres is this equivalent to?

10. A gallon is equal to 4·543 litres. How many cubic centimetres are contained in one pint?

11. A spherical glass bulb possesses a radius of 3 centimetres; calculate its capacity.

12. Calculate the length of the polar axis on the supposition that the earth is spherical, and that the actual metre is identical with the metre as defined.

13. A fine wire 255 millimetres in length weighs 0·172 grams. What length of such wire would it take to make a centigram 'rider'?

14. A piece of platinum foil measuring 10·5 centimetres by 1·5 centimetres weighs 0·723 gram. Into how many pieces, each weighing one decigram, may it be divided?

15. A piece of Swedish filter paper measuring 60 centimetres square, leaves on burning 0·1062 gram of ash. Calculate the amount of ash left on burning filters possessing the following radii: (*a*) 3 centimetres, (*b*) 4 centimetres, (*c*) 5 centimetres, (*d*) 6 centimetres, (*e*) 8 centimetres, (*f*) 10 centimetres.

16. A perfectly cylindrical tube 90 millimetres in length holds exactly one gram of water at 4° C. Calculate its internal diameter.

17. I require a perfectly spherical bulb to hold 300 cubic centimetres. What internal diameter must it have?

18. A cylindrical graduated tube 15 millimetres in diameter holds 25 cb. centimetres up to the hundredth division. Calculate the value in grams of water at 4° C. of one division. What will be the length between each division?

19. A flask, nominally of 1 litre capacity, is found to contain 997 grams of distilled water at 15° C., when the lowest point of the meniscus coincides with the graduation mark; (see table III) by how much do its contents fall short of their supposed value?

20. A 50 c.c. pipette delivers 50 grams of water at 16° C.; what is the true volume of the space up to the graduation mark?

21. In the verification of a Mohr's burette successive volumes of 10 c.c.'s of water, at 15° C., weighed 9·94 grm., 9·99 grm., 10·06 grm., 10·13 grm., 10·19. grm. What corrections should be applied to obtain the volumes delivered from the zero-mark to the 20, 40, and 50 c.c. marks respectively?

CONVERSION OF THERMOMETRIC SCALES.

(C. Centigrade ; F. Fahrenheit ; R. Reaumur.)

Fahrenheit to Centigrade $\frac{5}{9}(\text{F.}^\circ - 32) = \text{C.}^\circ$
Centigrade to Fahrenheit $\frac{9}{5}\,\text{C.}^\circ + 32 = \text{F.}^\circ$
Reaumur to Fahrenheit $\frac{9}{4}\,\text{R.}^\circ + 32 = \text{F.}^\circ$
Fahrenheit to Reaumur $\frac{4}{9}(\text{F.}^\circ - 32) = \text{R.}^\circ$
Centigrade to Reaumur $\frac{4}{5}\,\text{C.}^\circ = \text{R.}^\circ$
Reaumur to Centigrade $\frac{5}{4}\,\text{R.}^\circ = \text{C.}^\circ$

EXAMPLES.

1. What temperature on the Centigrade scale is equal to 212° F.?

$$212 - 32 = 108$$

$$\frac{180 \times 5}{9} = \frac{900}{9} = 100^\circ$$

Ans. = 100° C.

2. What temperature on the Centigrade scale is equal to 0° F.?

$$0 - 32 = -32$$

$$\frac{-32 \times 5}{9} = \frac{-160}{9} = -17^\circ{\cdot}77 \text{ C}$$

3. Express 60° C. on Fahrenheit's scale.

$$\frac{60 \times 9}{5} = \frac{540}{5} = 108$$

Ans. $108 + 32 = 140^\circ$ F.

4. Express − 15 C. on Fahrenheit's scale.

$$\frac{-15 \times 9}{5} = \frac{-135}{5} = -27$$

Ans. $-27 + 32 = +5^\circ$ F.

QUESTIONS.

22. Express the following temperatures in °C.

60° F.
80° R.
0° F.
0° R.
−15°·5 F.
500° F.
−10° R.
25°·5 R.
0°·2 F.

23. Express the following temperatures in °R.

15°·5 C.
60° F.
32° F.
1200° F.
−40° C.
240° C.
0°·25 C.
0°·0 F.
15°·0 F.

24. Express the following temperatures in °F.

4°·0 C.
15°·5 C.
60° C.
12° R.
0°·1 C.
80° R.
212° C.
360° R.
1°·0 C.

25. Bromine boils at 138°·7 F. What is the corresponding temperature on the Centigrade scale?

26. Ether boils at 34°·9 C., alcohol at 78°·4 C., and sulphuric acid at 338° C. What are the corresponding boiling-points on Fahrenheit's scale?

27. Mercury freezes at −38°·8 C. and boils at 357°·25 C. Calculate the corresponding temperatures on the scales of Reaumur and Fahrenheit.

28. Cast-iron melts at 1550° C., zinc at 423° C., lead at 334° C., tin at 235° C. Calculate these temperatures in °F.

29. At what point are the numbers on the scales of Fahrenheit and Celsius identical? To what temperature does this point correspond on the scale of Reaumur?

CORRECTION OF THERMOMETER READINGS.

Thermometer readings require, in general, to be corrected:

(1) For change in the zero-point.

(2) For the cooling of that portion of the thread not immersed in the heating medium (the emergent thread). For the most accurate work a correction is also applied for the want of uniformity of the bore of the capillary stem, generally by means of a table formed by calibration of the tube or by comparison of the individual thermometer with a standard instrument. Finally, the mercurial-thermometer readings, to be comparable, should all be reduced to air-thermometer readings by means of Table VII. (Appendix).

An approximate correction for the emergent thread may be obtained by means of the expression $\delta(t - t')n$, where δ the co-efficient of apparent expansion of mercury in glass = ·000154, t = the observed temperature on the thermometer, t' = the mean temperature of the cooled column as determined by an attached thermometer, and n = the length in degrees of the cooled column.

In ordinary cases δ = ·000143 gives a result nearer the truth than the actual coefficient; a useful table calculated by means of this constant is appended (Table VIII).*

EXAMPLES.

1. In the determination of the boiling-point of a sample of ethyl formate a thermometer is used indicating 0°·8 when plunged into melting ice. When the stem is entirely surrounded by vapour the reading taken is 55°. What is the corrected boiling-point?

---

* Several other formulæ have been proposed to calculate the correction required, but neither these nor the one given above give the true correction in all cases; for moderate values of n Table VIII. is fairly true if thermometers of the ordinary type are employed. See the article "Zur Korrection der Thermometerablesungen für den herausragenden Faden," by Dr. E. Rimbach, in the *Zeitschrift für Instrumentenkunde*, May 1890.

The zero of this thermometer has risen 0°·8, hence all readings must be diminished by this amount and we have 55° − 0°·8 = 54°·2 BP required.

2. With a thermometer reading 0°·2 in melting ice, the BP of propionic acid is indicated as 139°·2; the column is immersed in the vapour to the 70° mark and the temperature of the exposed part is 26°; what is the corrected BP? What is the corresponding H-thermometer temperature?

Correction for change of zero-point = −0°·2.

Correction for cooled column = + 1°·13 for n = 139·2 − 70 = 69·2 (70 nearly), and $t - t'$ = 139·2 − 26 = 113·2, while from Table VIII. for n = 70 and $t - t'$ = 110 and 120 the corrections are + 1°·10 and + 1°·20 respectively.

The required BP is therefore

$$139{\cdot}2 - 0^\circ{\cdot}2 + 1^\circ{\cdot}13 = 140^\circ{\cdot}13.$$

From Table VII. 139·85° mercury thermr. = 140° hydrogen thermr.; hence 140°·13 = (140 − 139·85)° = 140°·13 + 0°·15 = 140°·28 is the corresponding hydrogen-thermometer temperature.

QUESTIONS.

30. The indicated temperature of the vapour of boiling methyl acetate is 57°·9 when the thermometer is immersed in the vapour to the 100° mark; the same instrument reads 0°·5 in melting snow; what is the corrected boiling point?

31. During a fractionation of isobutyric acid 4 portions are collected (*a*) from 149°·5 to 150°·3 (*b*) from 150°·3 to 150°·9 (*c*) from 150°·9 to 151°·1 (*d*) 151°·1 to 151°·5 as indicated by a thermometer (standing at 0°·4 in clean melting ice), having 55° immersed in the vapour, temperature of outside column as given by a second thermometer being 27°. What are the corrected temperatures between which the four fractions pass over?

32. A sample of ethene dibromide distils over mostly between 130°·6 and 130°·7, n = 55 and t' = 11°·3. What is the corrected BP of this fraction? What is the corresponding temperature on the hydrogen thermometer scale?

33. Reduce the indicated BP's given below to temperatures on the hydrogen-thermometer scale.

N_2O_4 $21^\circ{\cdot}85$ ($n = 22$, $t' = 13^\circ{\cdot}5$)
$SiCl_4$ $58^\circ{\cdot}20$ ($n = 0$)
PCl_3 $76^\circ{\cdot}15$ ($n = 18{\cdot}2$, $t' = 26^\circ$)
$POCl_3$ $107^\circ{\cdot}30$ ($n = 0$).
$VOCl_3$ $127^\circ{\cdot}15$ ($n = 10$, $t' = 30^\circ$)

CORRECTION OF BAROMETER READINGS.

Observed barometric heights are reduced to the height of a column of mercury at 0° and at the level of the sea in latitude 45°, which would produce the same pressure.

The corrections needed for this reduction are :—

I. Correction for temperature, due to expansion of the mercury and the material of the scale.

Let m = coefficient of expansion of Hg, S = coefficient of linear expansion of the substance of the scale, h = the observed height of the barometer, and H = the corrected height; then $\mathbf{H} = h\left(\frac{1 + st}{1 + mt}\right)$

or approximately $\mathbf{H} = h\,\{1 - (m - s)t\}$

Hence the required correction is $-(m - s)t.h$.

With a brass scale we have $\mathbf{H} = h\,(1 - 0{\cdot}000162t)$

and the correction is $-0{\cdot}000162.t.h$;

and with a glass scale similarly

$$\mathbf{H} = h\,(1 - 0{\cdot}000157t)$$

and the correction is $-0{\cdot}000157.t.h$.

II. Correction for height above the sea-level and latitude, obtained as follows :—

If λ be the latitude, and x the height expressed in metres of the place of observation above the sea-level, the length of the column of mercury which produces the standard pressure is

$760{\cdot}000 = 1{\cdot}946 \cos 2\lambda + 0{\cdot}000149x$. mm. therefore if the observed height of the barometer be h the true or reduced height

$$\mathbf{H} = \frac{h \times 760}{760 + 1{\cdot}946 \cos 2\lambda + 0{\cdot}000149\, x}$$

If x be less than 100m. the term $0{\cdot}000149x$ may be omitted.

As these corrections are small, a result approximately true is obtained by taking

$$\mathbf{H} = h - 1{\cdot}946 \cos 2\lambda - 0{\cdot}000149\, x.$$

the greatest error so made being 0·04 mm. A further correction is required for the combined effects of error in adjustment of the scale and the depression of the column produced by capillarity, this correction should be given by the maker from comparison with a standard instrument.

EXAMPLE.

A Fortin barometer at latitude 52° and 21m. above sea-level stands at 754·34 mm. The instrument has a brass scale, the correction for index-error and capillarity is + 0·26 mm., and the temperature at time of observation is 16° C.; what is the reduced reading?

Neglecting quantities beyond the second place of decimals.

I. $$\begin{aligned} \Pi &= 754{\cdot}34\,(1 - 0{\cdot}000162.\, t) \text{ mm.} \\ &= 754{\cdot}34 - 754{\cdot}34 \times 0{\cdot}000162 \times 16 \text{ mm.} \\ &= 754{\cdot}34 - 1{\cdot}96 \text{ mm.} \\ &= 752{\cdot}38 \text{ mm.} \end{aligned}$$

II. $$\begin{aligned} \mathbf{H} &= \frac{\mathrm{H} \times 760}{760 + 1{\cdot}946 \cos 2\lambda + 0{\cdot}000149.\, x} \\ &= \frac{752{\cdot}38 \times 760}{760 + 1{\cdot}946 \cos 104^\circ + 0{\cdot}000149.\, 21.} \\ &= \frac{752{\cdot}38 \times 760}{760 + 1{\cdot}946\,(-0{\cdot}2419)} \\ &= \frac{752{\cdot}38 \times 760}{759{\cdot}53} = 752{\cdot}84 \text{ mm.} \end{aligned}$$

Hence true height of barometer, reduced to 0°C, sea-level, and latitude 45° = 752·84 + ·26 mm. = 753·10 mm.

QUESTIONS.

34. The barometer-readings taken during a gas-analysis with a Fortin barometer, of which the maker's correction was + 0·19 mm., were 754·83 mm., 756·21 mm., 757·39 mm., and 758·27 mm. The temperature of the instrument was throughout 18° C., what were the barometer-heights reduced to 0°C.?

35. Supposing the barometer to stand at 753·82 mm. at London (Lat. 51° 30′ N. T = 8°C)., Liverpool (Lat. 53° 25′ N. T = 14°C.), Madeira I. (Lat. 32° 45′ N. T = 20°C.), and Bombay (Lat. 19° 8′ N. T = 19°C.); what is the true pressure of the atmosphere at each of these places?

36. Fill in the reduced barometric heights, in column VI. of the annexed table. All the barometers have brass scales.

I. Temperature of barometer at the time of observation.

II. Height of place of observation above the sea-level.

III. Latitude of „ „

IV. Maker's correction.

V. Observed height of mercury column.

I.	II.	III.	IV.	V.	VI.
A. 8° C.	20 m.	45° N.	− 0·12 mm.	753·72 mm.	
B. 15° C.	357 m.	52° S.	− 0·35 mm.	761·08 mm.	
C. 13·5° C.	75 m.	63° N.	+ 0·08 mm.	755·59 mm.	
D. 17·2° C.	28 m.	25° S.	− 0·21 mm.	765·34 mm.	
E. 16·8° C.	234 m.	0°	+ 0·17 mm.	759·37 mm.	
F. 20° C.	998 m.	72° N.	+ 0·15 mm.	760·18 mm.	
G. 11° C.	105 m.	58° N.	− 0·23 mm.	762·15 mm.	

CORRECTION OF THE VOLUMES OF GASES FOR TEMPERATURE AND PRESSURE.

Law of Charles: — Gases under constant pressure expand $\frac{1}{273}$ part of their volume at 0° C. for every increase in temperature of 1° C.

Thus 273 volumes of any gas at 0° C.
become 274 „ „ 1° C.
„ 275 „ „ 2° C.
„ 276 „ „ 3° C.
„ $273 + t$ „ „ t°

This fraction $\frac{1}{273}$, or the slightly more accurate decimal fraction 0·003665, is termed the *coefficient of expansion of gases.*

EXAMPLES.

1. 10 c.c. of a gas are measured at 15° C. What volume will the gas occupy at 150° C.?

$$273 + 15 : 273 + 150 :: 10 : x$$

$$x = \frac{423 \times 10}{288} = 14{\cdot}69 \text{ c.c.}$$

2. 100 c.c. of hydrogen are measured at 100° C. How many cubic centimetres will the gas occupy at − 100° C.?

$$273 + 100 : 273 - 100 :: 100 : x$$

$$x = \frac{173 \times 100}{373} = 46{\cdot}37 \text{ c.c.}$$

3. What will be the volume at 25° C. of 252 c.c. of oxygen measured at 15° C.?

$$1 + (15 \times 0{\cdot}003665) : 1 + (25 \times 0{\cdot}003665) :: 252 : x$$

$$1{\cdot}054975 : 1{\cdot}091625 :: 252 : x$$

$$x = \frac{1{\cdot}091625 \times 252}{1{\cdot}054975} = 260{\cdot}75 \text{ c.c.}$$

By increasing the pressure upon a gas its volume is diminished : by diminishing the pressure the volume is increased.

Boyle's Law :—The volume of a gas at constant temperature is inversely proportional to the pressure to which it is subjected.

1. 1000 c.c. of hydrogen are measured under a barometric pressure of 740 mm. What will the volume become under the standard pressure of 760 mm.?

$$760 : 740 :: 1000 : x$$

$$x = \frac{740 \times 1000}{760} = 973{\cdot}6 \text{ c.c.}$$

2. A litre of air is measured at 0° C. and 760 mm. What volume will it occupy at 740 mm. and 15°·5 C.?

$$\left.\begin{array}{l} 273 : 273 + 15{\cdot}5 \\ 740 : 760 \end{array}\right\} :: 1000 : x.$$

$$x = \frac{288{\cdot}5 \times 760 \times 1000}{273 \times 740} = 1085{\cdot}34 \text{ c.c.}$$

Dalton's Law of Partial Pressures :—The pressure of a mixture of chemically indifferent gases and vapours is equal to the sum of the pressures which each would exert if it alone occupied the whole space.

EXAMPLES.

1. If 100 vols. of air consist of 20·66 O, 77·9 N, 0·03 CO_2, and 1·40 of aqueous vapour, and the barometer stands at 760 mm.; what is the partial pressure of each of these vapours and gases?

$$\text{Partial pressure of O} = \frac{760 \times 20{\cdot}66}{100} = 157{\cdot}01 \text{ mm.}$$

$$\text{,, ,, ,, N} = \frac{760 \times 77{\cdot}91}{100} = 592{\cdot}11 \text{ mm.}$$

$$\text{,, ,, ,, } CO_2 = \frac{760 \times 0{\cdot}03}{100} = 0{\cdot}23 \text{ mm.}$$

$$\text{,, ,, ,, } H_2O = \frac{760 \times 1{\cdot}40}{100} = 10{\cdot}64 \text{ mm.}$$

The pressure of a vapour in contact with its own liquid is always the same at the same temperature.

2. An eudiometer, graduated in mm. from the closed end, contains coal gas; pure boiled water is introduced until the mercury meniscus remains wet; the upper level of the mercury with gas dry stands at 400 mm., the lower level at 800 mm.; the average volume of 1 cm. of the tube = 1·66 c.c., barometer stands at 756 mm., temp. of air is 18°C. What are the volumes of the dry coal gas and of the vapour of water in the moist gas respectively, reduced to standard conditions?

Vol. of dry coal gas = $1{\cdot}66 \times 40{\cdot}0 = 66{\cdot}4$ c.c. at $756 - (800 - 400)$ or 356 mm. and 18°C.

$$\text{Hence vol. at } 0^\circ\text{C. and } 760 \text{ mm.} = \frac{66{\cdot}4 \times 356 \times 273}{760 \times 291}$$
$$= 29{\cdot}18 \text{ c.c.}$$

Tension of aqueous vapour at 18°C. = 15·33 mm.; hence upper level of mercury is depressed to $(400 \times 15{\cdot}33)$ mm. and vol. of aqueous vapour = $1{\cdot}66 \times 41{\cdot}536 = 68{\cdot}95$ c.c. at 15·33 mm. and 18°C., and this volume of a gas

$$= \frac{68{\cdot}95 \times 15{\cdot}33 \times 273}{760 \times 291} = 1{\cdot}304 \text{ c.c. at } 760 \text{ mm. and } 0^\circ\text{C.}$$

QUESTIONS.

37. 170 volumes of oxygen are measured at 10°C. What will the volume be on the temperature sinking to 0°C.?

38. A certain weight of air measures a litre at 0°C. How much will the air expand on being heated to 100°C.?

39. A gas has its temperature raised from 15° C. to 50° C.; at the latter temperature it measures 15 litres. What was the initial volume?

40. A volume of hydrogen measures 1500 cubic centimetres at 0° C. How many cubic centimetres will it measure at (*a*) 15°·5 C., (*b*) at 50° C., (*c*) at 100° C., and (*d*) at 300° C.? At what temperature will it measure exactly 1000 cubic centimetres?

41. The coefficient of expansion for gases for 1° C. is 0·003665. What is the coefficient for (*a*) 1° F., and (*b*) 1° R.?

42. A certain volume of air preserved at a constant temperature measures 150 cubic centimetres when the barometer stands at 760 millimetres. On the following day its volume is found to have decreased 1·52 cubic centimetres. Calculate the alteration in the height of the barometer which must have ensued.

43. A balloon containing 1200 cubic metres of coal gas under a pressure of 770 millimetres of mercury ascends until the barometer stands at 530 millimetres. What volume would the gas in the balloon now occupy supposing none to have escaped?

44. A certain quantity of nitrogen measures 155 cubic centimetres at 10° C., and under a pressure of 530 millimetres of mercury. What will the volume become at 18°·7 C., and under a pressure of 590 millimetres of mercury.

45. Calculate the temperature at which air possesses a density equal to that of hydrogen at 0° C.

46. Oxygen is passed into an eudiometer till the upper level of the mercury stands at 250 mm., level in trough at 780 mm. It is required to add double the quantity of hydrogen; if the tube be adjusted till the trough level becomes again 780 mm. and the average volume of 10 mm. of tube is 1·74 c.c., what will be the reduced volume of the added hydrogen, and what the reading of the upper level of the mercury in the eudiometer after the addition (Bar. 754 mm., T. 17·5° C.)?

47. Supposing the atmosphere to be saturated at 15° C., barometer 754 mm., what is the per centage volume of aqueous vapour contained in the air?

48. Defining the dew-point as the temperature at which the air would be saturated when containing the amount of vapour of water present at the time of observation, give the per centage volume of aqueous vapour present in the air when the dew-point is 15° C. and 5° C. respectively (Bar. 765 mm.).

49. A gas burette contains 53·2 c.c. of moist coal gas at 760 mm. pressure and 18·5° C.: find the volume of the dry gas under standard conditions.

50. 23·70 c.c. of dry nitrogen are contained in an absorptiometer, 5 c.c. of water are introduced and by agitation 0·07 c.c. of the gas is absorbed. The pressure is brought to that of the atmosphere, 757·3 mm., when reading the volumes, and the temperature remains at 16° C.: what is the volume of moist nitrogen indicated at the end of the experiment?

RELATIVE DENSITY OF SOLIDS, LIQUIDS, AND GASES; VAPOUR DENSITY.

THE specific gravity (sp. gr.) or relative density of a solid or liquid substance is the ratio of its mass to the mass of an equal volume of some liquid taken as unity.

The standard universally adopted is pure water at its maximum density. The number which expresses the relative density of a solid or liquid substance denotes, therefore, how much heavier or lighter the substance is than an equal bulk of water at 4° C.

1. The relative density of a solid is generally ascertained by :—

I. The hydrostatic balance method.

$$\text{Rel. dens.} = \frac{\text{Weight of substance } (W)}{\text{Weight of equal vol. water at } 4^\circ \text{ C.}} = \frac{W}{W - w}.$$

where w = weight of substance in water at 4° C.

If the solid be lighter, bulk for bulk, than water a sinker is employed of weight in water = x, and rel. dens. = d.

$$\text{Rel. dens.} = \frac{W}{W + x - w'}$$

where w' = weight of combination in water.

If the determination be made at t° C., then

$$\text{Rel. dens.} = \frac{W}{W - w} \times \text{rel. dens. of water at } t^\circ \text{ C.}$$

EXAMPLE.

A piece of iron sulphide (white pyrites) weighed in air 4·8934 grams : in water it weighed 3·8860 grams. Calculate its rel. dens.

$$\text{Rel. dens.} = \frac{4{\cdot}8934}{4{\cdot}8934 - 3{\cdot}8860} = \frac{4{\cdot}8934}{1{\cdot}0074} = 4{\cdot}857.$$

II. The specific gravity flask method.

If W = weight of substance in air, w' = weight of flask filled with water, w'' = weight of flask filled with substance and water; we have weight of substance in water = $w'' - w'$ and hence

$$\text{Rel. dens.} = \frac{W}{W - w'' + w'} \times \text{rel. dens. of water at } t^\circ \text{ C.}$$

2. The relative density of a liquid is commonly found by :—

I. The specific gravity flask method.

Let x = weight of the empty flask, w = weight of flask filled with water at t° C., w' = weight of flask filled with liquid under examination, then

$$\text{Rel. dens.} = \frac{w' - x}{w - x} \times \text{rel. dens. of water at } t^\circ \text{ C.}$$

II. Weighing an insoluble solid in water and in the liquid.

Let x = weight of solid in air, w = weight in water at t° C., w' = weight in liquid, then

$$\text{Rel. dens.} = \frac{x - w'}{x - w} \times \text{rel. dens. of water at } t^\circ \text{ C.}$$

III. The method of balanced liquid columns.

If h = height of column of water and h' = height of balancing column of liquid, then

$$\text{Rel. dens.} = \frac{h}{h'}.$$

EXAMPLES.

1. Find the rel. dens. of absolute alcohol from the following data :—

Weight of bottle empty	3·7200	grams.
„ filled with water .	7·9582	„
„ „ alcohol .	7·1508	„

$$\text{Rel. dens.} = \frac{7{\cdot}1508 - 3{\cdot}7200}{7{\cdot}9582 - 3{\cdot}7200} = \frac{3{\cdot}4308}{4{\cdot}2382} = 0{\cdot}8095.$$

2. A glass rod, weighing 13 grams in air, weighs 8 grams in water, and 3·8 grams in sulphuric acid; what is the sp. gr. of the sulphuric acid?

$$\text{Sp. gr.} = \frac{13 - 3{\cdot}8}{13 - 8} = \frac{9{\cdot}2}{5} = 1{\cdot}84.$$

Density of gases and vapours:—The density of any substance at a known temperature (and pressure, in the case of gases and vapours) is the mass of a unit of volume of the substance at that temperature (and pressure).

The sp. gr. or rel. dens. of a gas or vapour is the ratio of its mass to the mass of an equal volume of hydrogen measured at the same temperature and pressure.

The rel. dens. of a gas is commonly termed the density of the gas, and the rel. dens. of the vapour of any substance the vapour density of the substance.

One gram of hydrogen under standard conditions measures 11·1636 litres; this volume accordingly becomes a convenient unit of volume for measuring densities. Using this unit, the densities are expressed by the same numbers as the relative densities or specific gravities.

One litre of hydrogen gas at 0° C. and 760 mm.

barometric pressure and at the level of the sea and latitude 45° weighs 0·08958 gram.

3. The rel. dens. of a gas is determined by :—

I. Weighing a known volume of the gas by means of :—

A. A counterbalanced globe, filled by the evacuation method.

B. The displacement method : a bulb of known volume containing an inert gas is kept at a constant temperature while the experimental gas is passed in through one of the leading tubes in such a way as, so far as possible, to fill the bulb by the displacement of the contained gas.

C. The method of collecting in a light small flask over mercury (Bunsen).

II. The effusion method (Bunsen).

The rel. dens. varies directly as the square of the time of effusion of equal volumes.

EXAMPLE.

In one of Bunsen's experiments, a certain volume of air escaped under pressure through a minute orifice in 102·7 seconds; under exactly similar conditions, the same volume of CO_2 required 127·0 seconds to escape through the same orifice. What is the rel. dens. of CO_2 (air = 1)?

$$\frac{\text{Rel. dens. of } CO_2}{\text{Rel. dens. of air}} = \frac{127{\cdot}0^2}{102{\cdot}7^2} = \frac{16129}{10547} = 1{\cdot}5292 = \text{Rel. dens. of } CO_2.$$

4. The rel. dens. of a vapour is found usually by :—

I. *A.* The direct measurement of the volume of vapour produced by the evaporation in an enclosed space of a known weight of the substance—the principle of the methods of Gay Lussac and Hofmann.

B. The indirect measurement of the same quantity, the volume of an inert gas displaced being actually measured —the principle of Victor Meyer's method.

Or II. The weighing of a known volume of the vapour taken at an ascertained temperature and pressure—the methods of Dumas, and Deville and Troost.

If D = the required density of the vapour referred to H as unity, we have in case I. A.

$$D = \frac{w \, . \, 760 \, . \, (1 + 0{\cdot}00367 \; T)}{v \, . \, 0{\cdot}00008958 \, . \, (H - h) \, . \, (1 + kT)}, \quad \text{where}$$

w = weight of liquid taken, and hence weight of vapour formed.

v = observed volume of vapour in c.c.

H = reduced height of bar. at time of experiment.

h = reduced height of mercury in tube above that in cistern.

T = temperature of vapour.

k = coefficient of cubical expansion of glass for 1° C.

And in case I. *B*.

$$D = \frac{w \, . \, 760 \, . \, (1 + 0{\cdot}00367 \; T)}{v \, . \, 0{\cdot}00008958 \, . \, (H - p)}, \quad \text{where}$$

w = weight of liquid taken.

v = the observed volume of displaced gas in c.c.

H = reduced height of bar. at time of experiment.

p = vapour tension of water at temperature t° of measuring vessel.

T = temperature of water in collecting trough.

The methods under 4. II. for determining vapour density and under 3. I. for finding the rel. dens. of a gas require the following data:—

P = the weight of bulb in air empty.

P' = the weight of bulb filled with gas or vapour in air.

V = the capacity of bulb in c.c.

v = the volume of the residual air in c.c.

H = height of bar. and t = the temp. at which P' is found.

H' = height of bar. and T = the reduced temp. of the bath at the time of sealing or closing the bulb.

k = the coefficient of cubical expansion of the material of the bulb.

0·00367 = the coefficient of expansion at constant pressure of a gas.

Then $P' - P + \dfrac{0{\cdot}0012932\,.\,(V - v)\,H}{(1 + 0{\cdot}00367\,.\,t).\ 760}$ = the weight of vapour taken for $(V - v)$ is the volume occupied by the air displaced by the vapour or gas and the weight of the

displaced air $= \dfrac{0{\cdot}0012932.\ (V - v)\,H}{(1 + 0{\cdot}00367.\ t).\ \ 760}$;

(As v is generally small, any small differences between the pressure and temperature under which it is measured and H and t may be neglected.)

and the volume occupied by this weight at H' and T is

$\left[V(1 + k\,T) - v.\dfrac{1 + 0{\cdot}00367.\ T}{1 + 0{\cdot}00367.\ \ t}\right]$ which equals under

standard conditions

$$\left[V(1 + k\,T) - v.\frac{1 + 0{\cdot}00367.\ T}{1 + 0{\cdot}00367.\ \ t}\right]\cdot\frac{H'}{760.(1 + 0{\cdot}00367.\,T)}$$

hence the rel. dens. referred to air as unity is given by the formula

$$\frac{P' - P + \dfrac{0{\cdot}0012932.\ (V - v).\ H}{(1 + 0{\cdot}00367\,t).\qquad 760}}{\dfrac{\left[V(1 + k\,T) - v.\dfrac{1 + 0{\cdot}00367.\ T}{1 + 0{\cdot}00367.\ \ t}\right]\cdot\dfrac{H'}{760.(1 + 0{\cdot}00367.\,T)}.}{0{\cdot}0012932}}$$

if hydrogen be taken as unity 0·0012932 is replaced by 0·00008958 the weight of 1 c.c. of hydrogen in grams.

The expression $\frac{1}{1 + 0{\cdot}00367 . T}$ can be at once obtained from Table V. in the Appendix.

An approximate value for the rel. dens. of a gas or vapour is given by

$$D = \frac{P' - P + Vn^t}{(V - v)n^T} \cdot 14{\cdot}436.$$

in which

D = the required rel. dens. referred to hydrogen as unity.

n^t = the weight of 1 c.c. of air at t.

n^T = the weight of 1 c.c. of air at T.

EXAMPLES.

1. In a determination of the vapour density of heptane by Hofmann's method (I. A.), the following data were obtained:—

Weight of liquid taken . .	0·0769 gram.
Volume of vapour . . .	69·77 c.c.
Temperature	99·60°C.
Barometer	749·0 mm.
Height of mercury column .	493·4 mm.

Find the vapour density of heptane.

From table V. $\frac{1}{1 + 0{\cdot}00367.99\ 6} = \frac{0{\cdot}73232}{1}$

$$\text{and } (H - h) = 749{\cdot}0 - 493{\cdot}4 = 255{\cdot}6$$

Therefore, neglecting the expansion of the glass,

$$D = \frac{0{\cdot}0769 \times 760.1}{69{\cdot}77 \times 255{\cdot}6 \times 0{\cdot}73232 \times 0{\cdot}00008958} = 49{\cdot}96.$$

2. Find the vapour density of anthracene from the given data, determined by Victor Meyer's method.

Weight of anthracene taken = 0·0530 gram.
Temperature of water in measuring cylinder . 17·2°C.
Reduced height of barometer . . . . . . 720·8 mm.
Volume of air collected . . . . 7·8 c.c.

$$D = \frac{0{\cdot}0530 \times 760 \times (1 + 0{\cdot}00367 \times 17{\cdot}2)}{7{\cdot}8 \times 0{\cdot}00008958 \times (720{\cdot}8 - 14{\cdot}6)} = 86{\cdot}77.$$

3. Calculate the vapour density of the body furnishing the following data:—

Weight of empty globe, in air, 24·4722 grams.
Weight of globe sealed, with vapour, in air at 9° C. and 762 mm. } 25·0122 grams.
Temp. 215° C., bar. 762 mm., at time of sealing.
Capacity of the globe, 169·5 c.c.
Residual air, 12·5 c.c.

Our approximate formula is

$$D = \frac{P' - P + Vn^t}{(V - v)\,n^T} = 14{\cdot}436$$

$$\therefore D = \frac{(25{\cdot}0122 - 24{\cdot}4722) + (169{\cdot}5 \times 0{\cdot}001252 \cdot \frac{762}{760})}{(169{\cdot}5 - 12{\cdot}5) . 0{\cdot}000722 \cdot \frac{762}{760}} . 14{\cdot}436$$

$$= \frac{0{\cdot}5400 + 0{\cdot}2128}{157 . 0{\cdot}000722 . \frac{762}{760}} . 14{\cdot}436$$

$$= \frac{0{\cdot}7528 . 14{\cdot}436.}{157 . 0{\cdot}000722 . \frac{762}{760}.} = 95{\cdot}62.$$

From the more accurate formula

$$D = \frac{P' - P + \dfrac{0{\cdot}0012932 . (V - v) . H}{(1 + 0{\cdot}00367\,T) . \ 760.}}{\left[V(1 + kT) - v\dfrac{1 + 0{\cdot}00367 . T}{1 + 0{\cdot}00367 . \ t}\right] \dfrac{H' . 0{\cdot}00008958}{760 . (1 + 0{\cdot}00367\,T.)}}$$

Taking *k* for glass equal to 0·000023, we have

$$D=\frac{25{\cdot}0122-24{\cdot}4722+\dfrac{0{\cdot}0012932.(169{\cdot}5-12{\cdot}5).762.}{(1+0{\cdot}00367\times215)760}}{\left[169{\cdot}5(1+0{\cdot}000023\times215)-12{\cdot}5\,\dfrac{1+0{\cdot}00367\times215}{1+0{\cdot}00367\times9}\right]\dfrac{762.0{\cdot}00008958}{760.(1+0{\cdot}00367\times215).}}$$

$$=\frac{0{\cdot}5400+0{\cdot}1971}{[170{\cdot}3-21{\cdot}6]\,\dfrac{762}{760}\,.\,\dfrac{0{\cdot}00008958}{1{\cdot}789}.}$$

$$=\frac{0{\cdot}7371\times1{\cdot}789\times760}{148{\cdot}7\times0{\cdot}00008958\times762}=98{\cdot}73.$$

QUESTIONS.

51. Calculate the relative density of a solid substance from the following numbers:—

Weight of substance in air . . .	2·4554 grams.
„ „ water . . .	2·0778 grams.

52. Determine the relative density of gold from the following data:—

Weight of gold in air	4·6764 grams.
Loss of weight in water . . .	0·2447 grams.

53. Find the relative densities of the following substances:—

	Granite	*Marble*	*Hæmatite*
Weight in air.	409·82 grams.	53·2841 grams.	13.6287 grms.
„ water.	259·31 „ .	33·4020 „ .	10·9406 „ .

54. Determine the relative density of wood from the following numbers:—

Weights of: wood in air, 4 grams,; a silver sinker, 10 grams,; wood and sinker under water, 8·5 grams.
Relative density of silver = 10·5.

55. A platinum wire 10 cm. in length weighs 0·12 gram. The relative density of platinum being 21·275, calculate the diameter of the wire.

56. A glass bulb of 120 c.c. capacity weighs 14·5 grams. The relative density of the glass being 2·48, calculate the thickness of the walls of the bulb.

57. Faraday calculated that the gold contained in 4 sovereigns could be drawn into a wire long enough to surround the earth. The weight of a sovereign is 7·988 grams, and 91·66 $^{0}/_{0}$ of this is pure gold, possessing a relative density of 19·3. Assuming that the length of a quadrant of the earth is 10,000,857 metres, find the thickness of the wire.

58. A piece of bell-metal, weighing 7·550 grams in air, weighs 6·6635 grams when weighed under water.

Determine the percentage amount of copper and of tin in the piece on the assumption that no alteration in bulk has occurred in alloying the two metals.

Relative density of copper = 8·93; of tin = 7·292.

59. A piece of cast iron, the relative density of which is known to be 7·2, is suspected to have internal cavities.

Its weight is found to be 203·04 grams, and when suspended in water at 4° C. it is found to weigh 171·84 grams. What is the total volume of these cavities?

60. Find the relative density of calcium from the following determination by Bunsen:—

Weight of empty bottle	13·640	grams.
„ bottle filled with naphtha	20·275	„ .
„ „ partly „ „ .	16·650	„ .
„ „ „ „ and calcium	19·150	„ .
„ „ full of naphtha and „	21·576	„ .
Relative density of naphtha . . .	0·758	„ .

61. From the given data, calculate the relative densities of:—

Weights of	Substance in air.	Bottle + water.	Bottle + water and substance.
Quartz . .	3·445 grams.	75·103 grams.	77·248 grams.
Heavy-spar .	11·216 „	69·002 „	77·718 „
Calcite . .	34·151 „	80·201 „	101·824 „
Iron pyrites .	0·795 „	5·337 „	5·973 „

62. Calculate the relative density of sea water from the following data :—

Weight of bottle empty	3·5305	grams.
,, filled with sea water,	7·7849	,,
,, filled with water	7·6722	,,

63. From the given data, calculate the relative densities of the liquids given.

Weights of	Bottle empty.	Bottle filled with water.	Bottle filled with substance.
A. A mineral water . .	14·1256 gm.	111·1370 gm.	111·7050 gm.
B. Vanadyl trichloride .	1·7413 ,,	6·8880 ,,	11·2190 ,,
C. Chromyl dichloride .	3·5312 ,,	7·6649 ,,	11·4692 ,,
D. Alcohol	5·2013 ,,	20·2051 ,,	17·0876 ,,

64. A specific gravity flask holds 2,545 milligrams of alcohol, 42,740 of mercury, and 5,829 of sulphuric acid.

Calculate the relative density of the sulphuric acid and mercury, the density of the alcohol being 0·8095.

65. A solid weighs *in vacuo* 100 grams; in water 85 grams; and in another liquid 88 grams. What is the relative density of this liquid?

66. A piece of a certain metal weighs 3·7395 grams in air; 2·3545 grams in water; and 2·0896 grams in another liquid. Calculate the relative density of the metal and of the liquid.

67. A column of distilled water 100 mm. high is found to balance columns of (*a*) glycerine 79·3 mm. high, (*b*) olive oil 109·3 mm. high, (*c*) turpentine 114·9 mm. high. What are the relative densities of these three liquids?

68. When a mercury barometer registers 760 mm., a glycerine barometer indicates 8203 mm., and a water barometer 10,162 mm.; the vapour tension of water at the temperature of the air, 15° C., is 12·7 mm. of mercury. What are the relative densities of the mercury and glycerine?

69. Regnault obtained, by his method of counter-balanced glass globes, the following data, from which it is required to calculate the relative density of nitrogen (air = 1).

I. Balloon filled with air while immersed in melting ice. Height of barometer, reduced to 0° C., at the moment of closing the tap. . . . . H_0 = 761·19 mm.
Weight added to balloon . . . . . p = 1·487 gram.

II. Balloon evacuated. Pressure of residual air, when balloon is immersed in ice. . . . . h_0 = 8·43 mm.
Weight added to balloon . . . . P = 14·141 gram.
Air being replaced by nitrogen, same conditions.

I. H_0 = 758·55 mm.
p = 1·8725 gram.

II. h_0 = 2·18 mm.
P = 14·227 gram.

70. With the same apparatus, the figures given for hydrogen were :—

I. H_0 = 756·16 mm.
p = 13·301 gram.

II. h_0 = 3·40 mm.
P = 14·1785 gram.

With air = 1, find the relative density of hydrogen.

71. Calculate the density of thiophosphoryl fluoride from the following data :—

I. Capacity of glass bulb at 15·8° C. and 776 mm. . . . . 239·86 c.c.
Weight of bulb in air at 17·1° C. and 771 mm. . . . . 59·7543 grams.
Weight of bulb in air at 17° C. and 771 mm. filled with gas and residual nitrogen at 10·7° C. and 771 mm. . . . . 60·3954 grams.
Volume of residual nitrogen at 11·3° C. and 771 mm. . . . . 78·9 c.c.

II. Capacity of glass bulb at 15·8° C. and 776 mm. . . . . 239·86 c.c.
Weight of bulb in air at 15·8° C. and 776 mm. . . . . 59·7282 grams.
Weight of bulb in air at 15·8° C. and

778 mm. filled with gas and residual nitrogen at 7·7° C. and 778 mm.	60·5274 grams.
Volume of residual nitrogen at 9·6° C. and 777 mm.	43·4 c.c.

72. An experimental determination of the density of hydrofluoric acid under diminished pressure gave :—

Weight of bulb and caps in air at 19·7° C. and 772 mm.	244 0120 grams.
Weight of bulb and caps and vapour in air at 17·5° C. and 772 mm.	244·0025 „
Cocks turned off at 31·8° C.	
Bar 772·3 mm., manometer reading 106·2 mm.	
Weight of bulb and caps + water at 24·3° C.	528·18 grams.
Residual air, reduced to 0° C. and 760 mm.	3·58 c.c. „
Weight of 1 c.c. of air at 0° C. and 760 mm.	0·0012928 „
Coefficient of cubical expansion of platinum for 1° C.	0·000027 „
Sp. gr. of air, $H = 1$.	14·435

Hence find the rel. dens. of the vapour of hydrofluoric acid, under the conditions at closing the cocks, as compared with air, and with hydrogen.

73. From the tabulated data, calculate the corresponding relative densities of hydrofluoric acid at the given temperatures.

T°C.	*Height of Bar.*	*Percentage vol. of residual air.*	*Pressure of vapour.*
26·4°	756 mm.	1·51	745 mm.
27·8°	763 „	2·23	746 „
29·2°	762 „	1·55	750 „
32·0°	754·5 „	1·52	743 „
33·1°	770·5 „	2·64	750 „
33·8°	767 „	1·14	758 „
36·3°	751 „	1·58	739 „
38·7°	764 „	1·69	751 „

74. A determination of the density of methyl bromide made by Bunsen according to his method yielded the following data. Calculate the relative density of the compound ($H = 1$).

Vol. of gas, at 0·7464 m. and 16·8° C. . .	42·19 c.c.
Height of mercury above the level of the metal in trough.	0·0243 m.
Weight of the flask and gas.	7·9465 grams.
Weight of the flask and air.	7·8397 „
Temperature in balance case.	6·2° C.
Height of barometer.	0·7421 m.

75. Bunsen determined the times of effusion through a minute aperture of the same volume of gases as follows :—

	Air.	*Hydrogen.*	*Air.*	*Oxygen.*	*Air.*	*Carbon dioxide.*
(1)	105·5	29·7	102·5	108·5	102·7	127·0.
(2)	105·6	29·3	103	109	102·7	127·5.

Find the rel. dens. of each gas compared with air.

76. The data below were obtained in three determinations of the vapour density of P_4O_6 according to Hofmann's method; calculate the V.D. in each case, (A) Air = 1. (B) $H = 1$.

	I.	II.	III.
Weight of substance taken	0·1887 grams.	0·1887 grams.	0·1887 grams.
Temperature of tube and vapour	132° C.	159° C.	184° C.
Temperature of air . . .	20° C.	20° C.	20° C.
Barometer	770 mm.	769 mm.	769 mm.
Height of mercury column	625 mm.	616 mm.	605 mm.
Volume of vapour at T° C.	137·5 c.c.	139·6 c.c.	141·45 c.c.
Tension of mercury at T° C.	1·5 mm.	5·6 mm.	12 mm.

77. A series of experiments by Ramsay and Young, under varying conditions, yielded the following data, from which the vapour-density of acetic acid is to be found in each case (Hofmann's method). ($H = 1$).

Weight taken.	Reduced Temp.	Corrected pressure.	Volume.
A. 0·01126 gram.	50° C.	13·4 mm.	170·06 c.c.
B. 0·03565 „	78·4 „	63·2 „	137·8 „
C. 0·01126 „	118·2 „	84·05 „	45·15 „
D. 0·03565 „	162·5 „	373·1 „	37·0 „
E. 0·03565 „	184·1 „	791·6 „	18 „

78. In the determination of a vapour density by Gay-Lussac's method the following data were obtained:—

Weight of substance taken, 0·1163 grams. Temp. of bath, 215° C. Observed volume of vapour, 50·77 c.c. Barometer, 755·5 mm. Difference of height of mercury inside and outside of tube, 80·0 mm. Height of spermaceti column reduced to mm. of mercury, 16·9 mm. Required the sp. gr. of the vapour ($H = 1$); also the weight of one litre at 0° C. and 760 mm. barometric pressure, assuming the vapour to behave like a perfect gas.

79. Using a porcelain vessel, heated in a Perrot's furnace to 1027° C., Victor Meyer obtained the data given below, from which the vapour density is to be calculated.

	I.	II.
Weight of substance taken (Iodine)	0·0874 grams.	0·0847 grams.
Barometer	722·8 mm.	722·8 mm.
Temperature of the room	21·5° C.	21·5° C.
Volume of air displaced	13·7 c.c.	13·3 c.c.

80. From the tabulated data, obtained by Victor Meyer's method, find the sp. gr. of the vapour of each substance, referred (1) to air, (2) to hydrogen, as unity.

Substance.	Weight taken.	Temp. of room.	Bar.	Volume of air displaced.
A. $CHCl_3$	0·1008 gram.	16·5° C.	707·5 mm.	22 c.c.
B. CS_2	0·0495 „	16·5° C.	717·8 mm.	16·4 c.c.
C. OH_2	0·0102 „	16·1° C.	723·3 mm.	14·6 c.c.
D. Iodine	0·1105 „	16·0° C.	714·8 mm.	11·1 c.c.

81. The specific gravity of coal-gas is about 0·5 referred to air as unity, and air is 14·435 times heavier than hydrogen. Calculate from these data the weight of coal-gas, at 10° C. and 530 mm. pressure, required to fill a balloon having a capacity of 800 cu. m.

82. Calculate the vapour density ($H = 1$) of a hydride from the following numbers :—

Balloon with air, 40·7955 grams. Temperature, 11° C. Balloon with vapour, 41·0960 grams. Temperature of sealing, 173° C. Capacity of balloon, 189 c.c.

83. Calculate the vapour density of camphor vapour ($H = 1$) from the following numbers, obtained by Dumas according to his method :—

Temp. of air, 13·5° C. Bar. 742 mm. Temp. of bath at the moment of sealing the globe, 244°C. Increase of the weight of globe, 0·708 grams. Volume of mercury required to fill the globe, 295 c.c. Residual air *nil.*

84. In a series of determinations by Deville and Troost of the vapour density of sulphur, the following figures were obtained :—

	I.	II.	III.
Temperature of the air .	10° C.	15° C.	10° C.
Height of barometer . .	769·5 mm.	760 mm.	769·4 mm.
Difference of weighings .	−0·190 gram.	−0·176 gram.	−0·203 gram.
Volume of porcelain bulb .	281 c.c.	280 c.c.	303·5 c.c.
Residual air	3 c.c.	6 c.c.	3·5 c.c.
Temp. of bath (Zn vapour)	1040° C.	1040° C.	1040° C.

Find the vapour density in each case, taking air = 1. Coefficient of cubical expansion of porcelain = 0·0000108. (N.B. The second weighing gives a figure here less than the first with the empty bulb in air.)

85. Using a modification of Dumas' method, Friedel and Crafts obtained the following data, from which the vapour density of aluminic chloride is to be calculated :— Temp. of vapour, 398·2° C. Pressure of vapour, 0·97

atmosphere. Barometer height, 754·8 mm. Volume of globe, 250 c.c. Residual air, 245 c.c. at 10·3 mm. and 17·2° C. Excess of weight of globe, 0·8765 gram. Weight of air displaced 0·3020 gram.

AVOGADRO'S HYPOTHESIS; DENSITY AND MOLECULAR WEIGHT; VALENCY, EQUIVALENTS AND ATOMIC WEIGHTS.

According to *Avogadro's Hypothesis* equal volumes of gases, at the same temperature and pressure, contain the same number of molecules.

Hence it follows that the molecular weights of bodies in the state of gas or vapour are in the same ratio as their specific gravities or vapour densities: *e.g.* if H = 1, the sp. gr. of gaseous HCl. = 18·18.

Assuming the molecular weight of H to be 2, the molecular weight of HCl is 36·36.

The molecular weight of a gaseous element or compound may be thus defined; The *molecular weight* of a gaseous element or compound is a number which expresses how many times greater than two unit masses of hydrogen is the mass of the specified element or compound which occupies (under the same conditions of temperature and pressure) the same volume as is occupied by these two unit masses of hydrogen. The *maximum atomic weight* of an element is a number which expresses how many times greater is the smallest mass of that element which combines with other elements to form a compound gaseous molecule, than the smallest mass of hydrogen which combines with other elements to produce a compound gaseous molecule, such smallest mass of hydrogen being taken as unity. (Watts's *Dict.* I. p. 341.)

That property of an atom which determines the number of other atoms with which it can combine to form a compound molecule is termed its *valency* or atomic value. Valency is usually expressed as the number of hydrogen atoms, or atoms chemically equivalent to hydrogen, which one atom of the specified element can combine with or replace when in the same state as in the compound considered.

The *equivalent* of an element is the number expressing that weight of the element which will combine with or replace the unit weight of hydrogen.

Let E = the equivalent of any element, A = its atomic weight, and V = its valency in the compound used for determining the equivalent; the relations between these quantities are expressed by the equation $A = E \, . \, V$.

The numerical value of the molecular weight of any substance is obtained by the summation of the atomic weights of the component elements each multiplied by the number denoting how many of such atoms are contained in the molecule, *e.g.* the molecular weight of alcohol, C_2H_6O, is found thus $(12 \times 2) + (1 \times 6) + 16 = 24 + 6 + 16 = 46$.

QUESTIONS.

86. If the density of sulphuretted hydrogen = 1·791, ammonia = 0·597, nitrous oxide = 1·520, marsh gas = 0·555, chloroform = 4·20, and stannic chloride = 9·20, as compared with air, what are the molecular weights of these bodies taking the molecular weight of hydrogen as 2?

87. Determine the weight of one litre of the following simple gases and vapours at 0° and 760 mm., on the supposition that they can all exist as perfect gases at the standard temperature and pressure:—

Oxygen.
Chlorine.
Iodine.
Sulphur.
Phosphorus.
Nitrogen.
Sodium.
Arsenic.
Mercury.

88. Calculate the volume, at the standard temperature and pressure, of a kilogram of each of the following gases and vapours:—

Carbon monoxide.
Hydrogen sulphide.
Marsh gas.
Water.
Ethylene.
Oxysulphide of carbon.
Bromine.
Hydrochloric acid.

89. What weight of each of the specified substances is represented by the appended formulæ, taking one gram as the unit of weight?

Lead chloride, $PbCl_2$; Silicon fluoride, SiF_4;
Ferric chloride, $FeCl_3$; Methyl bromide, CH_3Br.

90. Find the density (air = 1) of:—Carbon monoxide, CO; Carbon bisulphide, CS_2; Sulphur trioxide, SO_3; Boron trifluoride, BF_3; Phosphorus pentafluoride, PF_5.

91. If the electro-chemical equivalent of: Oxygen = 7·98, Silver = 107·66, Chlorine = 35·37, Antimony = 39·86, and Copper = 31·59, and the hydrogen-replacing power of these elements in the compounds used in finding the equivalents be for one atom of the element taken, Oxygen 2, Silver 1, Chlorine 1, Antimony 3, and Copper 2 atoms; what are the atomic weights of these elements?

92. From the data given deduce the probable atomic weight of oxygen:

Gaseous compound.	Rel. dens. (air = 1).	Rel. dens. × 28·87 approximate mol. wt.	Molecular weight.	Analysis stated in parts by wt. per mol.
Carbon dioxide .	1·53	44·2	43·89	31·92 O + 11·97 C.
Sulphur dioxide .	2·25	64·9	63·90	31·92 O + 31·98 S.
Sulphur trioxide .	2·9	83·7	79·86	47·88 O + 31·98 S.
Carbon monoxide	0·97	27·97	28·93	15·96 O + 11·97 C.
Water	0·63	18·2	17·96	15·96 O + 2 H.
Nitric oxide . .	1·04	30·0	29·97	15·96 O + 14·01 N.

93. Find the most probable atomic weight of carbon from the appended experimental results:

Gaseous compound.	Rel. dens. (air = 1).	Analysis in parts by wt.
Marsh gas	0·555	11·97 C. + 4·0 H.
Methyl iodide . . .	4·883	11·97 C. + 126·53 I + 3·0 H.
Chloroform	4·20	11·97 C. + 106·11 Cl + 1·0 H.
Carbon monoxide . .	0·968	11·97 C. + 15·96 O.
Carbon bisulphide . .	2·645	11·97 C. + 63·96 S.

94. Find the molecular weights of the following bodies:

Cadmium at 940°, Rel. dens. = 3·94, (air = 1).
Phosphorus at 500°, Rel. dens. = 4·35, „
Mercury at 446°, Rel. dens. = 6·98, „

95. Select the most probable atomic weight for phosphorus as indicated by the given experimental results :—

Gaseous compound.	Rel. dens. (air = 1).	Analysis in parts by wt.
Phosphorus hydride	1·15	30·96 P. + 3·0 H.
Phosphorus chloride	4·88	30·96 P. + 106·11 Cl.
Triethyl phosphine oxide . .	4·60	{30·96 P. + 15·96 O. + 71·82 C. + 15·0 H.

How many atoms are there in the phosphorus molecule ?

DEDUCTION OF THE EMPIRICAL FORMULA OF A BODY FROM ITS PERCENTAGE COMPOSITION; FORMULÆ OF MINERALS.

In order to calculate the empirical formula of a compound, divide the percentage amount of each constituent by its corresponding atomic weight : divide each of the quotients so obtained by the lowest number, and reduce them to their simplest ratios.

EXAMPLES.

1. A body on analysis yielded the following percentage composition :—

Carbon	27·273
Oxygen	72·727
	100·000

Calculate its empirical formula.

The atomic weight of carbon = 12 ; that of oxygen = 16.

Then

$$C = \frac{27.273}{12} = 2.2727$$

$$O = \frac{72.727}{16} = 4.5454$$

The simplest relation between the carbon and oxygen is at once seen to be as 1 to 2, since

$$2.2727 : 4.5454 :: 1 : 2.$$

Hence the formula of the compound is CO_2.

2. A compound of hydrogen and nitrogen was found to possess the following percentage composition. Calculate its formula.

Nitrogen . . .	82·353
Hydrogen . . .	17·647
	100·000

The atomic weight of N = 14, and of H = 1.

$$N = \frac{82.353}{14} = 5.882$$

$$H = \frac{17.647}{1} = 17.647$$

The simplest ratio between the nitrogen and hydrogen is as 1 to 3, since

$$5.882 : 17.647 :: 1 : 3.$$

Hence the formula of the body is NH_3.

3. A compound of iron and oxygen possesses the following percentage composition. Calculate its formula.

Iron	70·01
Oxygen	29·99
	100·00

At. weight of Fe = 56·0. At. weight of O = 16.

Then

$$\frac{70{\cdot}01}{56} = 1{\cdot}2514$$

$$\frac{29{\cdot}99}{16} = 1{\cdot}8744$$

The ratio between $1{\cdot}2514 : 1{\cdot}8744 :: 1 : 1{\cdot}5$

The simplest ratio, in whole numbers, is therefore 2 : 3. Hence the formula of the body is Fe_2O_3.

FORMULÆ OF MINERALS.

There exist many groups of minerals of which the individual members are composed of equal numbers of atoms similarly combined, and which possess the same or nearly the same crystalline form; such groups are termed isomorphous groups, and the minerals forming each group are said to be isomorphous with each other.

Isomorphous minerals may replace each other without affecting the exterior form of the mineral partially replaced. As the percentage amount of the elements in such minerals is different in each case, mixed minerals do not admit of being directly represented by a simple formula derived as above from the percentage composition.

It is the practice to represent minerals of this type by a general formula obtained by considering the particular isomorphous substance present in greatest quantity as the typical substance and reducing the quantities of the replacing bodies to equivalent quantities of the typical body, when the formula may be at once obtained by the ordinary means.

When possible, mineral analyses are ordinarily reported as percentages of oxides, and in the calculation these oxides are considered as the isomorphous components to be reduced to terms of that present in greatest amount.

As an example we may consider the case of ankerite: an analysis of which by Schrötter yielded the following results:

CaO	26·90
MgO. . . .	7·84
FeO	19·91
MnO. . . .	1·82
CO_2	43·05
	99·52

CaO is the oxide present in greatest quantity : we therefore reduce the other oxides to their equivalents of CaO and adding all together we obtain the typical composition of the mineral considered as if it were a Ca compound; thus :—

$\frac{7\cdot84 \times 56}{40} = 10\cdot98 =$ CaO equivalent to MgO present.

$\frac{19\cdot91 \times 56}{72} = 15\cdot48 =$ CaO equivalent to FeO present.

$\frac{1\cdot82 \times 56}{70} = 1\cdot46 =$ CaO equivalent to MnO present.

Hence total typical oxide present ($M''O$)

parts.

$= 26\cdot90 + 10\cdot98 + 15\cdot48 + 1\cdot46 =$ 54·82

combined with CO_2 . . . . 43·05

By the ordinary method

$M''O$. . . $\frac{54\cdot82}{56} = 0\cdot98$ nearly, and $\frac{0\cdot98}{0\cdot98} = 1$

CO_2 . . . . $\frac{43\cdot05}{44} = 0\cdot98$ nearly $\frac{0\cdot98}{0\cdot98} = 1$

Hence typical composition is $M''O.CO_2$ or $M''CO_3$, where M'' represents Ca, Mg, Fe, and Mn.

The formula of ankerite may therefore be written (Ca, Mg, Fe, Mn) CO_3.

QUESTIONS.—Deduce the formulæ of the following substances:—

96.	Hydrogen	5·88
	Oxygen	94·12
		100·00

97.	Nitrogen	30·43
	Oxygen	69·57
		100·00

! 98.	Iron	70·01
	Oxygen	29·99
		100·00

99.	Carbon	20·00
	Oxygen	26·67
	Sulphur	53·33
		100·00

100.	Potassium	28·73
	Hydrogen	0·73
	Sulphur	23·52
	Oxygen	47·02
		100·00

! 101.	Magnesium	9·76
	Sulphur	13·01
	Oxygen	26·01
	Water	51·22
		100·00

102.	Zinc	22·70
	Sulphur	11·15
	Oxygen	22·28
	Water	43·87
		100·00

† 103.	Calcium	38·72
	Phosphorus	20·00
	Oxygen	41·28
		100·00

† 104.	Sodium	32·79
	Aluminium	13·02
	Fluorine	54·19
		100·00

105.	Potassium	45·95
	Nitrogen	16·45
	Oxygen	37·60
		100·00

106.	Aluminium	16
	Sulphur	28
	Oxygen	56
		100

107.	Copper	57·46
	Carbon	5·43
	Hydrogen	0·91
	Oxygen	36·20
		100·00

† 108.	Hydrogen	3·18
	Oxygen	33·88
	Nitrogen	14·84
	Sulphur	16·95
	Nickel	31·15
		100·00

109.	Carbon	85·71
	Hydrogen	14·29
		100·00

110.	Carbon	92·3
	Hydrogen	7·7
		100·0

111.	Carbon	19·04
	Hydrogen	4·76
	Sulphur	25·40
	Oxygen	50·80
		100·00

112.	Carbon	74·07
	Hydrogen	8·64
	Nitrogen	17·29
		100·00

113.	Carbon	46·66
	Hydrogen	4·26
	Nitrogen	5·20
	Oxygen	5·92
	Platinum	18·26
	Chlorine	19·70
		100·00

! 114. Show that a mineral having the following percentage composition is represented by the formula $MOCO_2$ when M signifies a metal of the magnesium family :

Lime	28·4
Magnesia	12·3
Iron monoxide	12·3
Manganese monoxide	1·9
Carbon dioxide	44·4
	99·3

115. The mineral kerolite gave the following numbers on analysis. Calculate its formula :

SiO_2	MgO	H_2O
46·96	31·26	21·22 = 99·44.

116. A specimen of cobalt-bloom was found to have the following composition. Determine its formula :

As_2O_5	CoO	FeO	H_2O
38·43	36·52	1·01	24·10 = 100·06

117. Calculate the formula of soda-feldspar from the following analysis :—

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
68·45	18·71	0·27	0·50	0·18	0·65	11·24 = 100·00.

118. Calculate the formula of labradorite from the following analysis :—

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O
52·52	30·03	1·72	12·58	0·19	4·51 = 101·55.

TO CALCULATE THE PERCENTAGE COMPOSITION OF A COMPOUND FROM ITS FORMULA.

First calculate the molecular weight of the compound by adding together the sums of its atomic weights. Thus the formula for water is H_2O; its molecular weight is therefore 17·96.

$$\begin{array}{llr} \text{Atomic weight of H.} = 1 & 1 \times 2 = & 2 \\ \text{Atomic weight of O.} = 15{\cdot}96 & & 15{\cdot}96 \\ \hline & & 17{\cdot}96 \end{array}$$

In order to calculate from the molecular weight of the compound the percentage amount of its constituents—that is, to determine how much of each constituent is contained in 100 parts of the compound—multiply the amounts of the several constituents in the compound by 100, and divide each of the products by the molecular weight of the compound. Thus, to calculate the amounts of hydrogen and oxygen contained in 100 parts of water :—

$$H = \frac{2 \times 100}{17{\cdot}96} = 11{\cdot}14$$

$$O = \frac{16 \times 100}{17{\cdot}96} = 88{\cdot}86$$

$$\overline{\underline{100{\cdot}00}}$$

Table I. in the Appendix gives the atomic weights of the elements according to the most trustworthy determinations.

QUESTIONS.

Calculate the percentage composition of the following compounds :—

119. Water	$H_2 O$.
120. Potassium chlorate	$K Cl O_3$.
121. Mercury monoxide	$Hg O$.
122. Potassium nitrate	$K N O_3$.
123. Sodium nitrate	$Na N O_3$.
124. Barium sulphate	$Ba S O_4$.
125. Calcium carbonate	$Ca C O_3$.
126. Silver chloride	$Ag Cl$.
127. Magnesium pyrophosphate	$Mg_2 P_2 O_7$.
128. Potassium platinum chloride	$2 (K Cl) + Pt Cl_4$.
129. Sodium thiosulphate	$Na_2 S_2 O_3 + 5 H_2 O$.
130. Magnetic oxide of iron	$Fe_3 O_4$.
131. Hausmannite	$Mn_3 O_4$.
132. Copper pyrites	$Cu_2 S + Fe_2 S_3$.
133. Stromeyerite	$Ag Cu S$.
134. Stilbite	$Ca O Al_2 O_3 . 6 Si O_2 + 5 H_2 O$.
135. Idocrase	$9 (2 Ca O . Si O_2) . 2 (2 Al_2 O_3 . 3 Si O_2)$.
136. Spodumene	$3 (Li_2 O . Si O_2) . 4 (Al_2 O_3 . 3 Si O_2)$.
137. Sphene	$Ca Si O_3 . Ca Ti O_3$.
138. Pyromorphite	$3 Pb_3 P_2 O_8 . Pb Cl_2$.
139. Ethyl alcohol	$C_2 H_6 O$.
140. Cane sugar	$C_{12} H_{22} O_{11}$.
141. Xylene	$C_8 H_{10}$.
142. Cymene	$C_{10} H_{14}$.
143. Silicon ethyl	$Si \left\{ \begin{array}{l} C_2 H_5. \\ C_2 H_5. \\ C_2 H_5. \\ C_2 H_5. \end{array} \right.$
144. Potassium thiacetate	$C_2 H_3 K O S$.
145. Potassium ferrocyanide	$K_4 Fe C_6 N_6$.
146. Kreatin	$C_4 H_9 N_3 O_2 + H_2 O$.
147. Rosaniline	$C_{20} H_{21} N_3 O$.
148. Strychnine	$C_{21} H_{22} N_2 O_2$.

✓

CHEMICAL EQUATIONS; TO CALCULATE THE AMOUNT OF MATERIAL REQUIRED TO PRODUCE A GIVEN WEIGHT OF ANY SUBSTANCE OR THE QUANTITY OF THE SUBSTANCE PRODUCED BY THE DECOMPOSITION OF A KNOWN WEIGHT OF THE MATERIAL.

Chemical equations:--The results of any chemical actions are represented by equations in which the signs + – and = are used in the same sense as in algebra, so far as regards the weights of matter represented by the symbols.

The meaning of such an equation will be best shown by examples.—

1. $H_2SO_4 + BaCl_2 = BaSO_4 + 2\ HCl.$

This equation indicates not only that sulphuric acid and barium chloride react to produce barium sulphate and hydrochloric acid, but, further, that the molecular weight of sulphuric acid reacts with the molecular weight of barium chloride to produce the molecular weight of barium sulphate and twice the molecular weight of hydrochloric acid; hence 98 parts by weight of sulphuric acid react with 208 parts by weight of barium chloride to form 233 parts by weight of barium sulphate and 73 parts by weight of hydrochloric acid gas.

The number of *atoms* of each element must be the same on either side of the equation, consequently the total number of *atoms* must be the same on either side. The numbers of *molecules* before and after a reaction are not necessarily the same.

2. $H_2 + Cl_2 = 2\ HCl.$

Here, as in (1), it is indicated that 2 parts by weight of hydrogen combine with 71 parts by weight of chlorine to produce 73 parts by weight of hydrochloric acid. But the equation signifies more: as we know the molecular weights of all the reacting bodies and products it shows that a molecule of hydrogen combines with a molecule of chlorine to form two molecules of hydrochloric acid gas. If we state the molecular weights in grams we know from the equation that 22·4 litres of hydrogen combine with 22·4 litres of chlorine to yield 44·8 litres of hydrochloric acid, for two grams of hydrogen measure 22·4 litres approximately at the standard conditions and, by Avogadro's hypothesis, equal numbers of molecules under the same conditions occupy equal volumes.

EXAMPLES.

1. How much oxygen can be obtained by the decomposition of 100 grams of mercury monoxide? The symbol for mercury monoxide is HgO: hence its molecular weight is 216.

$$\begin{array}{lr} Hg = & 200 \\ O = & 16 \\ \hline & 216 \\ \hline \end{array}$$

When mercury monoxide is heated, it is completely resolved into oxygen and metallic mercury,

$$2HgO = 2Hg + O_2,$$

432 parts of mercury monoxide giving 400 of mercury and 32 of oxygen. If, therefore, 32 grams of oxygen are evolved by the decomposition of 432 grams of mercury monoxide, how many grams of oxygen will be evolved by the decomposition of 100 grams of mercury monoxide?

$$432 : 100 :: 32 : x.$$
$$x = 7{\cdot}407.$$

7·407 grams of oxygen will therefore be evolved on heating 100 grams of mercury monoxide.

2. I want 100 lbs. of oxygen: how many lbs. of potassium chlorate must I take?

The formula of potassium chlorate is $KClO_3$. Its molecular weight is therefore

$$\begin{array}{lr} K = & 39{\cdot}1 \\ Cl = & 35{\cdot}5 \\ O_3 = (16 \times 3) & 48{\cdot}0 \\ \hline & 122{\cdot}6 \\ \hline \end{array}$$

This substance on being heated eventually decomposes into potassium chloride and oxygen.

$$2K\,Cl\,O_3 = 2K\,Cl + 3O_2.$$

That is, 96 lbs. of oxygen are evolved on heating 245·2 lbs. of potassium chlorate. Then how many lbs. of potassium chlorate are required to yield 100 lbs. of oxygen?

$$96 : 100 : 245{\cdot}2 : x.$$
$$x = 255{\cdot}4 \text{ lbs.}$$

Hence it would require 255·4 lbs. of potassium chlorate to yield 100 lbs. of oxygen.

3. How many cubic centimetres of oxygen and hydrogen, measured at 10° C. and 770 mm. pressure, can be obtained by the decomposition of 1 gram of water?

The symbol for water is H_2O, its molecular weight is 18. The weight of hydrogen yielded by a gram of water is

$$18 : 1 :: 2 : x$$
$$x = 0{\cdot}1111 \text{ gram.}$$

The weight of oxygen is

$$18 : 1 :: 16 : x$$
$$x = \underline{0{\cdot}8889}$$
$$1{\cdot}0000 \text{ gram.}$$

1000 cubic centimetres of hydrogen at 0° C. and 760 mm. weigh 0·08936 grams. Then what volume would 0·1111 gram of hydrogen occupy?

$$0{\cdot}08936 : 0{\cdot}1111 :: 1000 : x.$$
$$x = 1243{\cdot}28 \text{ c.c. of hydrogen.}$$

This at 10° and 770 mm. would measure

$$\left.\begin{array}{l} 273 : 273 + 10 \\ 770 : 760 \end{array}\right\} :: 1243{\cdot}28 : x.$$
$$x = 1272{\cdot}09 \text{ c.c.}$$

1000 cubic centimetres of oxygen at 0° C. and 760 mm. weigh (16 × 0·08936 gram) = 1·42976 grams. Then what volume would 0·8889 grams occupy?

$$1{\cdot}42976 : 0{\cdot}8889 :: 1000 : x.$$
$$x = 621{\cdot}713 \text{ c.c. of oxygen.}$$

This at 10° C. and 770 mm. would measure

$$\left.\begin{array}{l} 273 : 273 + 10 \\ 770 : 760 \end{array}\right\} :: 621{\cdot}713 : x$$
$$x = 636{\cdot}116 \text{ c.c.}$$

Therefore, a gram of water on being decomposed would yield at 10° C. and 770 mm. pressure, 1908·206 c.c. of mixed gases consisting of

Hydrogen . .	1272·09	c.c.
Oxygen . . .	636·116	„
	1908·206	

QUESTIONS.

149. How much potassium chlorate is needed to furnish 1 lb. of oxygen?

150. I require 2 kilograms of oxygen: how much (*a*) mercury monoxide, (*b*) potassium chlorate, (*c*) manganese dioxide, (*d*) sulphuric acid, shall I need?

151. On completely decomposing by heat a certain weight of potassium chlorate, I obtain 20·246 grams of potassium chloride. What weight of potassium chlorate did I take, and how much oxygen was evolved?

152. A gas bag has a capacity of 45 litres: how much manganese dioxide containing 70 per cent. of MnO_2 is required to fill it with oxygen at 15° C. and 760 mm. barometric pressure?

153. 132·74 kilograms of hydrogen are needed to inflate a balloon. What weight of zinc and sulphuric acid will be required to produce this quantity of gas?

154. Iron, zinc, and sulphuric acid diluted so as to contain 20 per cent. of real acid (SO_4H_2), are supplied to you. Find the amount of these materials required to produce the above quantity of hydrogen, (1) by the action of sulphuric acid upon iron, (2) by the action of sulphuric acid upon zinc.

155. What weight of potassium chlorate is needed to furnish oxygen sufficient to burn the hydrogen evolved by the action of water upon 200 grams of sodium?

156. How many cubic centimetres of oxygen and hydrogen measured at 12° C. and under a pressure of 762 mm. of mercury can be obtained by the electrolysis of 10 grams of water?

157. 100 grams of steam is passed over 1000 grams of red-hot iron wire. Required the volume of hydrogen evolved measured at 10° C. and 742 mm. pressure, and the weight of iron oxide produced.

158. 77 per cent. of the weight of the air, freed from moisture and carbonic acid, consists of nitrogen. Calculate the weight of (*a*) metallic copper, and (*b*) of phosphorus required to abstract the oxygen from 1 lb. of air.

159. Required the weight of ammonia and of chlorine needed to produce a litre of nitrogen.

160. What quantities of nitre and Chili saltpetre respectively will be required to obtain the maximum quantity of nitric acid by reaction with 140 kilos. of 97 per cent. sulphuric acid?

! 161. How much nitre and sulphuric acid shall I need to prepare nitric acid enough to neutralize exactly 5 lbs. of chalk?

162. Calculate the volume of nitrogen monoxide at 15° C. and 740 mm. produced on heating 30 grams of ammonium nitrate.

163. What weight of copper is required to yield a litre of nitrogen dioxide at 0° C. and 760 mm.?

164. At the ordinary temperature and pressure water absorbs 50 per cent. of its weight of ammonia. Calculate the amount of sal-ammoniac and quicklime needed to produce 10 kilograms of *Liquor Ammoniæ.*

165. Coal contains about 2 per cent. of nitrogen. Assuming that 75 per cent. of this amount escapes as ammonia on distillation, calculate the amount of coal required to furnish the sal-ammoniac needed to produce the 10 kilograms of *Liquor Ammoniæ.*

166. Calculate the weight of air required to burn a ton of coal possessing the following percentage composition :—

Carbon, 88·42 ; Hydrogen, 5·61 ; Oxygen, 5·97.

167. How much marble and hydrochloric acid containing 22 per cent. HCl are needed to yield 10 litres of carbon dioxide at 15° C. and 760 mm. barometric pressure?

168. According to Boussingault, a square metre of leaf will decompose in sunlight 1·108 litres of carbon dioxide in an hour. Calculate in tons the amount of carbon assimilated in an hour by a million trees, each possessing 100,000 leaves, and each leaf containing 25 square centimetres. Calculate the volume of the carbon so assimilated on the assumption that it possesses a sp. gr. of 1·6.

! 169 How many litres of (1) hydrogen and of (2) carbonic oxide gases at 10° C. and 750 mm. can be obtained by the decomposition of 100 grams of steam by passing it over red-hot charcoal?

170. I require 10 litres of carbon monoxide at 0° C. and 760 mm. pressure. How many grams of (1) oxalic acid, (2) of formic acid, and (3) of potassium ferrocyanide shall I need?

171. Required the weight in grams of sodium acetate to yield 10 litres of methane at 0° and 760 mm.

172. Manchester coal-gas contains 35 per cent. by volume of marsh gas. Calculate the weight of this gas in a gasometer holding 100,000 cubic feet of coal-gas.

173. Calculate the weight in kilos. of air needed, and of carbon dioxide and water formed, by the complete com-

bustion of 10,000 litres of Manchester coal-gas possessing the following composition by volume :—

Hydrogen	45·58
Marsh gas	34·90
Carbon monoxide	6·64
Ethylene	4·08
Butylene	2·38
Sulphuretted hydrogen	0·29
Nitrogen	2·46
Carbonic acid	3·67
	100·00

174. 100 grams of pure silver cyanide are shaken up with 120 grams of hydrochloric acid containing 26·1 per cent. of HCl. Required the amount of silver chloride produced, and the percentage amount of hydrocyanic acid in solution.

175. Required the weight of manganese dioxide containing 60 per cent. MnO_2 to liberate all the iodine from 100 grams of potassium iodide.

176. A manufacturer of bleaching powder requires 10 tons of chlorine. How much salt, manganese containing 59 per cent. of the dioxide, and sulphuric acid containing 58 per cent. of real acid, will he need?

177. What weight of hydrochloric acid gas is produced in the manufacture of 100 tons of salt cake? What volume of gas escapes supposing the manufacturer to condense only 92 per cent. of the quantity evolved?

178. 5·75 grams of silver nitrate are added to 5·75 grams of a solution of hydrochloric acid containing 10·22 per cent. H Cl. How much silver is precipitated and how much remains in solution?

179. What weight of bleaching powder can be theoretically produced from 150 tons of manganese containing 68 per cent. of the dioxide?

180. Required the weight of potassium chlorate yielded by the chlorine evolved from 100 tons of manganese containing 60 per cent. of the dioxide.

181. What weight of potassium bromate can be obtained by neutralizing 520 grams of bromine with potash?

182. Iodic acid may be obtained by passing a stream of chlorine through water containing iodine in suspension. How much iodine and chlorine will be needed to prepare 100 grams of iodic acid?

183. Required the weight of copper and sulphuric acid needed to yield 3 litres of sulphurous acid at the standard temperature and pressure.

! 184. A vitriol-maker prepares 100 tons of vitriol of specific gravity 1·6, containing 70 per cent. of acid: how many tons of pyrites containing 42 per cent. of sulphur must for this purpose be burnt? Supposing that 3 per cent. of the theoretical yield of sulphur remained unburnt in the pyrites, what would be the difference in the production of sulphuric acid?

185. What volume of oxygen at 10° C. and 743 mm. of mercury can be obtained by the decomposition of a litre of sulphuric acid possessing a density of 1·854 at 0° C.?

186. What weight of iron sulphide will be needed to yield a litre of hydrogen sulphide at 0° C. and 760 mm., and how much air will be required to burn this gas completely to water and sulphur dioxide?

† 187. 1 gram of phosphorus is to be converted into the pentachloride. How many litres of chlorine at 0° C. and 760 mm. are required?

188. How much crystallized microcosmic salt must be ignited to furnish a gram of sodium metaphosphate?

! 189. An alkali-maker consumes 300 tons of salt per week: he divides three-quarters of his yield of soda-ash equally for the preparation of soda crystals, bicarbonate, and solid caustic containing 70 per cent. Na_2O. What weight of sulphur will he need to use weekly, and what is the theoretical weekly yield of the four products of manufacture?

190. Required the weight of limestone needed to convert 50 tons of soda crystals into bicarbonate.

! 191. 100 grams of pure iron is burnt in excess of (1) oxygen and (2) chlorine. What is the weight of oxide and chloride produced?

X

COMBINATION AND DECOMPOSITION OF GASEOUS BODIES.

EXAMPLES.

1. 4 litres of hydrogen are mixed with 5 litres of chlorine, and the mixture exploded. What volume of hydrochloric acid gas is produced? Which gas, and how much of it remains in excess?

From the equation

$$\begin{array}{rcl} H_2 + Cl_2 & = & 2HCl \\ \text{2 volumes} + \text{2 volumes} & = & \text{4 volumes} \end{array}$$

it is evident that 1 volume of hydrogen combines with 1 volume of chlorine to form 2 volumes of hydrochloric acid gas. Therefore 4 litres of hydrogen would require 4 litres of chlorine, and would form 8 litres of hydrochloric acid gas, 1 litre of chlorine remaining uncombined.

2. 150 cubic centimetres of oxygen are mixed with 400 cubic centimetres of hydrogen and the mixture exploded. What volume of steam is produced? Which gas, and how much of it, remains uncombined?

From the equation

$$\begin{array}{rcl} 2\,H_2 + O_2 & = & 2\,H_2O \\ \text{4 vols.} + \text{2 vols.} & = & \text{4 vols.} \end{array}$$

it is evident that 150 cubic centimetres of oxygen would require 300 cubic centimetres of hydrogen, and yield 300 cubic centimetres of steam, 100 cubic centimetres of hydrogen remaining in excess.

3. 100 cubic centimetres of ammonia gas are completely decomposed by a series of electric sparks, yielding 200 cubic centimetres of mixed hydrogen and nitrogen: an excess of oxygen is next added, when the volume of mixed gases is found to amount to 290 cubic centimetres. The mixture is now exploded, when 65 cubic centimetres of gas remain. Show from these data that the symbol for ammonia is NH_3.

The total volume of the mixed gases before the explosion was 290 cubic centimetres; after the explosion 65 cubic centimetres remain. Hence (290 − 65) = 225 cubic centimetres of oxygen and hydrogen have disappeared to form water, and two-thirds of this contraction gives the amount of hydrogen in the mixture, and hence in the 200 cubic centimetres resulting from the decomposition of the 100 cubic centimetres of ammonia gas. $\frac{2}{3}$ of 225 = 150 cubic centimetres. Hence in the 200 cubic centimetres of the gas, 150 cubic centimetres were hydrogen, the remaining 50 being nitrogen. The gases are therefore mixed in the proportion of 1 volume of nitrogen to 3 volumes of hydrogen, and hence the symbol for ammonia is NH_3.

QUESTIONS.

! 192. 20 litres of hydrogen are mixed with 10 litres of chlorine. Which gas remains in excess? How many litres of hydrochloric acid are produced?

† 193. One cubic foot of hydriodic acid is decomposed by an excess of bromine. How many cubic feet of hydrobromic acid are formed?

† 194. The iodine in 100 volumes of hydriodic acid is liberated in succession by chlorine and by oxygen. How many volumes of chlorine and how many volumes of oxygen are required?

195. 50 cubic centimetres of hydrogen are exploded with 75 cubic centimetres of oxygen. Required the total volume of the gases after the explosion, measured at 150° C. and 760 mm. pressure.

196. How many litres of oxygen are contained in 3 litres of nitrogen peroxide (N_2O_4)?

197. An unknown volume of hydrogen sulphide required 110·34 cubic centimetres of chlorine for complete decomposition. What was the volume of the hydrogen sulphide?

198. How many cubic centimetres of hydrogen and nitrogen are contained in a litre of ammonia gas?

† 199. *V* volumes of a hydrocarbon $C_n H_{2n}$ are submitted to combustion. How many volumes of oxygen are required for its complete combustion, and how many volumes of carbonic anhydride are generated?

200. How many litres of air at 0° and 760 mm. are required for the complete combustion of 10 litres of (1) marsh gas, (2) olefiant gas, (3) acetylene?

201. 5 litres of chlorine are mixed with 5 litres of carbon monoxide. What volume of phosgene gas is produced, and how much hydrochloric acid and carbon dioxide would be produced by the decomposition of this gas with water?

202. What volume of arsenic is contained in a litre of oxide of cacodyl vapour measured at 500° C.?

GAS ANALYSIS CALCULATIONS.

The processes employed in gas analysis fall naturally under the heads :—

I. Proximate analysis, effected by the successive absorption of the various constituents of a gaseous mixture by suitable reagents.

Ultimate analysis, performed by the combustion of the gaseous mixture and calculation of the quantity of each element present from the observed alteration in volume due to the combustion, and the quantities of CO_2 and residual gas resulting therefrom. The combustion method in most cases allows the proximate composition of the mixture to be obtained indirectly; *e.g.* a mixture of x c.c. H, y c.c. CH_4, and z c.c. C_2H_2 yields the following data : A = original volume of mixture, B = contraction due to combustion, C = volume of CO_2 produced by the combustion.

From the equations

(1) $2\ H_2$ (2 vols. gas) $+\ O_2$ (1 vol. gas) $=\ 2\ H_2O$ (liquid).

(2) CH_4 (1 vol. gas) $+\ 2\ O_2$ (2 vols. gas) $=\ CO_2$ (1 vol. gas) $+\ 2\ H_2O$ (liquid).

(3) $2\ C_2H_2$ (2 vols. gas) $+\ 5\ O_2$ (5 vols. gas) $=\ 4\ CO_2$ (4 vols. gas) $+\ 2\ H_2O$ (liquid).

we have

$$A = x + y + z.$$

$$B = \tfrac{3}{2}x + 2y + \tfrac{5}{2}z.$$

$$C = y + 2z.$$

Hence

$$y = 2B - 3A. \quad z = \frac{3A - 2B + C}{2}. \quad x = \frac{5A - 2B - C}{2}.$$

x, y, and z are thus all expressed in terms of the measured quantities A, B, and C and can therefore be readily found.

It is required to measure the comparative quantities of gas present before and after an experiment in both I. and II. Three quantities require to be taken into account in such measurements, namely : (*a*) the volume of the gas, V; (*b*) its temperature, t (or absolute temperature $273 + t = T$); (*c*) its pressure, P. With reference to the measurement of V, T, and P four cases occur among common methods of gas analysis :—

(*A*). T and P are kept constant, V alone requires to be measured. Many technical processes, *e.g.* Orsat's method, follow this plan.

(*B*). V and T are maintained throughout the same, P is the measured quantity. Regnault's and derived processes use this method.

(*C*). The ratio $\frac{T}{P}$, termed the disgregation of the gas, is always brought to the same value, V is the recorded quantity. Doyère's method furnishes an example of this type.

(*D*). Analysis by the eudiometer and absorption tube needs the observation of all these variables, *P*, *V*, and *T*.

In (*A*) and (*C*) the observed volumes are in the direct ratio of the volumes reduced to standard conditions and hence may be directly compared; in (*B*) the measured pressures vary directly as the corrected volumes and can therefore be substituted for the latter in all calculations of the relative composition of the gas sample; in (*D*) all volumes must be reduced to some standard conditions before they can be compared.

EXAMPLES.

1. A heating-gas, made by working coke-gas producers with air and steam, yielded on analysis the following data:—

(*a*) Volume of gas employed	97·7 c.c.
(*b*) Vol. after absorption of CO_2 by potash . .	87·5 c.c.
(*c*) Vol. after absorption of CO by cuprous chloride	68·6 c.c.
(*d*) Vol. taken from (*c*) for estimation of H . .	59·3 c.c.
(*e*) Vol. after addition of air	98·8 c.c.
(*f*) Vol. after combustion with palladium asbestos in capillary tube	80·5 c.c.

Assuming the pressure and temperature to have remained constant during the analysis, calculate the percentage composition of the gas.

CO_2 absorbed by potash $= 97·7 - 87·5 = 10·2$ c.c.

$$\text{hence \% of } CO_2 = \frac{10·2 \times 100}{97·7} = 10·45.$$

CO absorbed by cuprous chloride $= 87·5 - 68·6 = 18·9$ c.c.

$$\text{hence \% of CO} = \frac{18·9 \times 100}{97·7} = 19·34.$$

Contraction on combustion $= 98·8 - 80·5 = 18·3$ c.c.

From equation $2\ H_2 + O_2 = 2\ H_2O$, it is seen that $\frac{2}{3}$ of observed contraction represents vol. of H present;

$$\text{hence vol. of H in } 59{\cdot}3 \text{ c.c. } (d) = \frac{18{\cdot}3 \times 2}{3} = 12{\cdot}2 \text{ c.c.}$$

$$\text{and } \therefore {}^{\circ}\!/_{\circ} \text{ of H in gas} = \frac{12{\cdot}2 \times 68{\cdot}6 \times 100}{59{\cdot}3 \times 97{\cdot}7} = 14{\cdot}44.$$

By difference, the °/ₒ of N is

$$100 - 10{\cdot}45 - 19{\cdot}34 - 14{\cdot}44 = 55{\cdot}77.$$

The percentage composition is then :—

Carbon dioxide	10·45	per cent.
Carbon monoxide . . .	19·34	„
Hydrogen	14·44	„
Nitrogen	55·77	„

2. A determination of the composition of air by Frankland and Ward's modification of Regnault's process supplied these figures (V and T are constant in this method):

(*a*) Air alone :—

Height of Hg. in barometer	673·0 mm.
Height of mark on measuring tube. .	383·0 mm.

(*b*) Air + hydrogen :—

Height bar.	945·0 mm.
„ mark	383·0 mm.

(*c*) After explosion :—

Height bar.	763·3 mm.
„ mark	383·0 mm.

Hence *pressures* are :—(*a*) 290·0 mm. (*b*) 562·0 mm. (*c*) 380·3 mm.; and the *corrected volumes* are in the same ratio as the *observed pressures*, therefore the percentage of oxygen present in the sample of air is

$$\frac{\frac{562{\cdot}0 - 380{\cdot}3}{3} \cdot 100}{290} = \frac{60{\cdot}56 \times 100}{290} = 20{\cdot}88.$$

3. Find the composition of a sample of coal-gas from the data given (Bunsen.)

	Volume.	Pressure.	Temperature °C.
A. Gas taken	134·3	0·7285 m.	14·5
After KOH absorption .	131·1	0·7317 m.	17·8
After pyrogallate absorption	130·6	0·7293 m.	17·5

A portion of the residue was treated in an absorption-tube with H_2SO_4 containing excess of SO_3, and then washed with KOH.

	Volume.	Pressure.	Temperature °C.
B. Portion taken.	97·3	0·6923 m.	18·5
After absorption of ethylene, propylene, and benzene-vapour . . .	93·2	0·6835 m.	18·0

A part of the residue from *B* was then exploded in the eudiometer.

	Volume.	Pressure.	Temperature °C.
C. Part taken.	150·9	0·1774 m.	18·4
After addition of O. . .	281·5	0·3041 m.	18·9
After further addition of air.	472·3	0·4942 m.	19·0
After explosion	425·5	0·4485 m.	17·8
After absorption of CO_2 .	407·7	0·4375 m.	18·0
On addition of H . . .	561·7	0·5888 m.	19·3
After explosion	367·5	0·3965 m.	19·6

The remainder of the gas from *A* was then similarly analysed.

	Volume.	Pressure.	Temperature °C.
D. Portion taken for analysis	139·8	0·1623 m.	15·2
After addition of O. . .	275·8	0·2963 m.	15·7
After further addition of air	446·6	0·4704 m.	13·3
After explosion	407·0	0·4296 m.	14·1
After absorption of CO_2 .	383·0	0·4236 m.	16·8
Residue + H.	592·8	0·6296 m.	17·1
After explosion	424·0	0·4629 m.	17·2

All the volumes given in this example require to be reduced to some common temperature and pressure; taking 0° C. and 1 m. pressure for standards, we have :—

A. Gas taken = 92·91; after KOH absorption = 90·06;

$$\text{hence } {}^\circ/_\circ \text{ of } CO_2 = \frac{(92{\cdot}91 - 90{\cdot}06)\ 100}{92{\cdot}91} = \frac{285}{92{\cdot}91} = 3{\cdot}07.$$

After absorption by alkaline pyrogallate, remaining vol. = 89·51, hence °/₀ of

$$O = \frac{(90{\cdot}06 - 89{\cdot}51)\ 100}{92{\cdot}91} = \frac{0{\cdot}55 \times 100}{92{\cdot}91} = 0{\cdot}59.$$

B. Part taken = 63·08; after absorption of ethylene propylene, and benzene-vapour by SO_3 = 59·75; hence

$${}^\circ/_\circ \text{ of these constituents} = \frac{(63{\cdot}08 - 59{\cdot}75) \times 89{\cdot}51 \times 100}{63{\cdot}08 \times 92{\cdot}91} = \frac{3{\cdot}33 \times 89{\cdot}51 \times 100}{63{\cdot}08 \times 92{\cdot}91} = 5{\cdot}09.$$

C. Portion taken = 25·1; after addition of O = 80·1; after addition of air = 218·2; after explosion = 179·2; hence contraction = 218·2 − 179·2 = 39·0. (1)

After absorption of CO_2 produced = 167·4; hence vol. of CO_2 = 179·2 − 167·4 = 11·8 (2)

After addition of H = 308·9; after explosion = 135·9; hence second contraction = 173. (3)

The incombustible residue of N from (2) is therefore, 167·4 − $\frac{173}{3}$ = 167·4 − 57·66 = 109·74, of which 0·7904

$(218{\cdot}2 - 80{\cdot}1) = 109{\cdot}15$ belongs to added air, hence N in $25{\cdot}1$ vols. taken $= 109{\cdot}74 - 109{\cdot}15 = 0{\cdot}59$ vols.; therefore

$$\text{°/}_\circ \text{ of N in gas} = \frac{0{\cdot}59 \times 59{\cdot}75 \times 89{\cdot}51 \times 100}{25{\cdot}1 \times 63{\cdot}08 \times 92{\cdot}91} = 2{\cdot}15.$$

Combustible gas $= 25{\cdot}1 - 0{\cdot}59 = 24{\cdot}51$; and this consists of x vols. H $+ y$ vols. $CH_4 + z$ vols. CO.

From the equations :—

$$2\,H_2 + O_2 = 2\,H_2O.$$

$$CH_4 + 2\,O_2 = CO_2 + 2\,H_2O.$$

$$2\,CO + O_2 = 2\,CO_2.$$

$$\text{we have, contraction } 39 = \tfrac{3}{2}\,x + 2\,y + \tfrac{1}{2}\,z \qquad (a)$$

$$CO_2 \text{ formed } 11{\cdot}8 = y + z. \qquad (b);$$

$$\text{and total volume } 24{\cdot}51 = x + y + z. \qquad (c);$$

$$\text{hence } x \left\{\text{from } (b) \text{ and } (c)\right\} = 12{\cdot}71.$$

Solving (a) and (b) for z, we have :—

$$39 = 19{\cdot}06 + 2\,y + \tfrac{1}{2}\,z$$

$$23 = \qquad 2\,y + 2\,z$$

$$\text{hence } \frac{3\,z}{2} = 23{\cdot}6 + 19{\cdot}06 - 39 = 3{\cdot}66.$$

$$\text{and } z = \frac{3{\cdot}66 \times 2}{3} = 2{\cdot}44.$$

From (b) $y + z = 11{\cdot}8$

$$\text{so } y = 11{\cdot}8 - z = 11{\cdot}8 - 2{\cdot}44 = 9{\cdot}36.$$

$$\text{Therefore °/}_\circ \text{ of H} = \frac{12{\cdot}71 \times 59{\cdot}75 \times 89{\cdot}51 \times 100}{25{\cdot}1 \times 63{\cdot}08 \times 92{\cdot}91} = 46{\cdot}21.$$

$$\text{°/}_\circ \text{ of } CH_4 = \frac{9{\cdot}36 \times 59{\cdot}75 \times 89{\cdot}51 \times 100}{25{\cdot}1 \times 63{\cdot}08 \times 92{\cdot}91} = 34{\cdot}03.$$

$$\text{and °/}_\circ \text{ of } CO_2 = \frac{2{\cdot}44 \times 59{\cdot}75 \times 89{\cdot}51 \times 100}{25{\cdot}1 \times 63{\cdot}08 \times 92{\cdot}91} = 8{\cdot}87.$$

D. Portion taken containing all the combustible gases = 21·5 ; after addition of O = 77·3 ; after addition of air = 200·4 ; after explosion = 166·2 ; hence contraction = 34·2. (1)

After absorption of CO_2 produced, vol. = 152·9 ; hence CO_2 = 166·2 − 152·9 = 13·3. (2)

After addition of H to residue, vol. = 351·3 ; after explosion 184·8 ; hence second contraction = 166·5. (3)

The contraction on explosion

$$(1) = \frac{34{\cdot}2 \times 89{\cdot}51 \times 100}{21{\cdot}5 \times 92{\cdot}91} = 153{\cdot}2$$ per cent. of the volume of the original gas.

The CO_2 produced

$$(2) = \frac{13{\cdot}3 \times 89{\cdot}51 \times 100}{21{\cdot}5 \times 92{\cdot}91} = 59{\cdot}60$$ per cent. of the same.

Contraction due to CH_4, CO, and H, from C. (1),

$$= \frac{39 \times 59{\cdot}75 \times 89{\cdot}51 \times 100}{25{\cdot}1 \times 63{\cdot}08 \times 92{\cdot}91} = 141{\cdot}8$$ per cent. of original vol.; hence contraction due to ethylene, propylene, and benzene, = 153·2 − 141·8 = 11·4 per cent. of vol. of original gas.

Similarly, CO_2 produced from CH_4 and CO, from C (2)

$$= \frac{11{\cdot}8 \times 59{\cdot}75 \times 89{\cdot}51 \times 100}{25{\cdot}1 \times 63{\cdot}08 \times 92{\cdot}91} = 42{\cdot}90$$ per cent., and so vol. of CO_2 produced from ethylene, propylene, and benzene, = 59·60 − 42·90 = 16·70 per cent. of vol. of original gas.

The percentage of ethylene, propylene, and benzene-vapour, present in the original gas is 5·09. (*B*).

Let x = percentage of C_2H_4, y = percentage of C_3H_6, and z = percentage of C_6H_6 ; then, from the equations :—

$$C_2H_4 + 3 . O_2 = 2CO_2 + 2H_2O.$$

$$2C_3H_6 + 9 . O_2 = 6CO_2 + 6H_2O.$$

$$2C_6H_6 + 15 . O_2 = 12CO_2 + 6H_2O.$$

we have contraction $11{\cdot}4 = 2x + \frac{5}{2}y + \frac{5}{2}z.$ (4)

and vol. of CO_2 $16{\cdot}70 = 2x + 3y + 6z;$ (5)

also vol. of gases $5{\cdot}09 = x + y + z.$ (6)

$$\text{From (4) and (6)}\quad \left.\begin{aligned} 11{\cdot}4 &= 2x + \tfrac{5}{2}y + \tfrac{5}{2}z \\ 12{\cdot}72 &= \tfrac{5}{2}x + \tfrac{5}{2}y + \tfrac{5}{2}z \end{aligned}\right\}$$

$$\text{whence } 1{\cdot}32 = \tfrac{1}{2}x$$

$$\text{and } x = 2{\cdot}64\ {}^{\circ}/_{\circ} \text{ of } C_2H_4.$$

$$\text{From (5) and (6)}\quad \left.\begin{aligned} 16{\cdot}70 &= 5{\cdot}28 + 3y + 6z \\ 5{\cdot}09 &= 2{\cdot}64 + y + z \end{aligned}\right\}$$

$$\text{or}\quad \left.\begin{aligned} 11{\cdot}42 &= 3y + 6z \\ 2{\cdot}45 &= y + z \end{aligned}\right\}$$

$$\text{or}\quad \left.\begin{aligned} 11{\cdot}42 &= 3y + 6z \\ 14{\cdot}70 &= 6y + 6z \end{aligned}\right\}$$

whence $3y = 3{\cdot}28$ and $y = 1{\cdot}09\ {}^{\circ}/_{\circ}$ of C_3H_6.

Again, $y + z = 2{\cdot}45 \quad \therefore z = 2{\cdot}45 - 1{\cdot}09 = 1{\cdot}36\ {}^{\circ}/_{\circ}$ of C_6H_6.

Tabulating our results, the percentage composition of coal gas is :—

Carbon dioxide		3·07.
Oxygen		0·59.
Absorbed by SO_3. 5·09 $^{\circ}/_{\circ}$	Ethylene	2·64.
	Propylene	1·09.
	Benzene-vapour	1·36.
Nitrogen		2·15.
Hydrogen		46·21.
Marsh-gas		34·03.
Carbon monoxide		8·87.

QUESTIONS.

203. Calculate the percentage composition of a sample of atmospheric air from the following numbers :—

	Volume.	Pressure.	Temperature °C.
Air employed	863·7	0·5576 m.	5·5
After addition of H . . .	1006·7	0·6911 m.	5·5
After explosion	800·7	0·4914 m.	5·6

204. A gaseous mixture containing oxygen, nitrogen, and carbonic acid, yielded the following numbers on analysis. Calculate the proportion of the constituent gases in 100 volumes of the mixture (Bunsen) :—

	Volume.	Pressure.	Temperature °C.
Original gas	171·2	0·6240 m.	13·5
After absorption of carbonic acid	167·3	0·6196 m.	13·5
After absorption of oxygen .	147·0	0·6058 m.	13·9

205. Determine the amount of aqueous vapour in a sample of air which yielded the following numbers on analysis (Bunsen) :—

Air saturated with moisture.

Lower level Hg. stands at.	565·9
Upper level in eudiometer	317·3
Vol. corresponding to 317·3	292·7
Meniscus correction	0·4
Air temperature	20·2° C.
Height of barometer	0·7469 m.

Same volume of air dried by Ca Cl_2.

Lower level Hg. stands at	565·9
Upper level in eudiometer	310·7
Vol. corresponding to 310·7	286·0
Meniscus correction	0·4
Air temperature	20·2 °C.
Height of barometer	0·7474 m.

206. Calculate the composition by volume of water from the following eudiometric synthesis :—

A. Hydrogen saturated with moisture.
B. Hydrogen + Oxygen saturated with moisture.
C. Residue after explosion saturated with moisture.

	A.	B.	C.
Observations at lower level of Hg	771·8	768·2	771·9
Observations at upper level in eudiometer	238·0	435·0	332·0
Corresponding volume	262·5	468·3	360·8
Barometer	0·7540 m.	0·7540 m.	0·7540
Thermometer	12·1°	12·6°	13·0°
Corresponding tension of aqueous vapour	10·5 mm.	10·9 mm.	11·2 mm.

207. Find the volume of each constituent contained in one volume of methyl ether from the data below, and deduce its empirical formula:—

	Volume.	Pressure.	Temperature.
A. Gas taken	50·6	0·1419 m.	1·4°C.
After addition of oxygen	199·8	0·3112 m.	2·6°C.
After explosion	172·4	0·2738 m.	3·7°C.
After absorption of CO_2	132·8	0·2409 m.	3·9°C.
After addition of H	547·3	0·6955 m.	2·6°C.
After explosion	466·6	0·6126 m.	1·5°C.
B. Gas taken	79·6	0·3140 m.	4·0°C.
After addition of oxygen	327·2	0·5615 m.	5·0°C.
After explosion	268·7	0·4915 m.	4·9°C.
After heating to 99·5°	418·1	0·6752 m.	99·5°C.
After cooling	268·2	0·4914 m.	3·7°C.
After absorption of CO_2	193·3	0·4188 m.	0·7°C.

208. Find the formula of nitrous oxide from the analytical results given:—

	Volume.	Pressure.	Temperature.
Gas taken	140·2	0·2175 m.	14·4°C.
After addition of H	248·4	0·3219 m.	14·4°C.
After explosion	191·4	0·2664 m.	14·0°C.
After addition of O	228·8	0·2931 m.	12·8°C.
After explosion	160·6	0·2253 m.	13·7°C.

209. A gaseous mixture collected from Hekla a month after an eruption yielded the following figures: find its percentage composition:

	Volume.	Pressure.	Temperature.
Gas taken	114·9	0·6944 m.	20·4°C.
After absorption with MnO_2 .	112·9	0·6958 m.	20·4°C.
After absorption with KOH .	108·1	0·7092 m.	20·6°C.
Gas decanted into eudiometer	136·7	0·3460 m.	20·6°C.
After explosion with (H_2+O)	137·2	0·3452 m.	20·7°C.
After addition of H	190·4	0·3980 m.	20·5°C.
After explosion	152·7	0·3585 m.	20·3°C.
After absorption with KOH .	148·9	0·3665 m.	18·9°C.

210. Find the percentage volume of H, SH_2, CO_2, N, CO, and CH_4 present in a fumarolle-gas giving on analysis:—

	Volume.	Pressure.	Temperature.
Gas taken	94·0	0·6945 m.	13·3°C.
After absorption of H_2S . .	73·7	0·6728 m.	13·6°C.
After absorption of CO_2 . .	46·1	0·6502 m.	13·6°C.
Gas decanted into eudiometer	96·8	0·3093 m.	13·1°C.
After addition of air. . . .	243·0	0·4534 m.	13·6°C.
After explosion	172·0	0·3839 m.	13·7°C.
After treatment with KOH .	168·6	0·3902 m.	13·1°C.

211. From the tabulated data, calculate the percentage amount of nitrogen present in each body analysed, and give the volumes, reduced to standard conditions, of the nitrogen and nitric oxide respectively in each case.

Measured in Frankland and Ward's apparatus.

Substance taken.	Volume in c.c.	Temperature.	Pressure N + NO	Pressure N.
A. 0·1263 gm.	13·79	18°C.	451 mm.	423 mm.
B. 0·0832 "	22·32	20°C.	411 "	378 "
C. 0·0827 "	22·32	24°C.	416 "	373 "
D. 0·0856 "	22·32	29°C.	396 "	375 "
E. 0·0878 "	13·5	19°C.	597 "	582 "
F. 0·1259 "	9·02	20°C.	408 "	405 "

212. Find the composition of marsh gas from the figures given below, obtained by Thomas's modification of Frankland and Ward's apparatus.

Temperature constant at 15·4° C.
Gas taken at 118·5 mm. pressure.
After addition of oxygen, pressure = 357·8 mm.
Pressure after explosion = 121·12 mm.
Pressure after absorption of CO_2 = 2·32 mm.

213. Calculate the percentage of CO_2 by volume contained in a sample of air which gave the accompanying data—10 c.c. of baryta solution agitated in a flask, containing the air, of 618 c.c. capacity, required 6·0 c.c. of normal oxalic acid for neutralization, of which 1 c.c. equals 1 c.c. of CO_2 at 0° C. and 760 mm.; bar. 726 mm., temp. 21° C. The same amount of baryta solution directly titrated with normal oxalic acid required 8·8 c.c.

214. To a solution of baryta sufficient alcoholic solution of phenolphthalein is added to produce a distinctly pink coloration; 1 c.c. of the solution = 0·104 c.c. carbon dioxide. A volume of 25 c.c. of the coloured solution becomes decolorized on the aspiration of 540 c.c. of air through it, owing to the absorption of CO_2; find percentage of CO_2 present.

215. An analysis of a specimen of coal-gas is made by (1) successive absorption of carbon dioxide, ethylene (propylene, butylene), benzene, oxygen, and carbon monoxide by means of Hempel's pipettes; (2) combustion of the hydrogen in a palladium-asbestos tube; (3) combustion of the methane by red-hot copper oxide with estimation of the carbon dioxide produced by titration. From the subjoined figures find the composition by volume of the sample analysed:

	Volume of gas employed	99·1 c.c.
(1)	Volume after absorption by KOH	97·7 c.c.
	Volume after treatment with Br water	93·9 c.c.
	Volume after treatment with fuming NO_3H	92·9 c.c.
	Volume after alkaline pyrogallol absorption	92·6 c.c.
	Volume after treatment with cuprous chloride	86·5 c.c.

(2)

Non-absorbable gas used for H estimation	40·6 c.c.
Non-absorbable gas + air	99·0 c.c.
Volume after combustion	65·7 c.c.

(3) Residue of 65·7 c.c. is burned by air and copper oxide, and CO_2 titrated by baryta-water and oxalic acid.

Gas measures 65·7 c.c. at 736 mm. and 20° C.
Baryta-water, 1 c.c. = 1·04 c.c. oxalic acid = 1·04 c.c. methane.

Baryta-water employed	50 c.c.
Oxalic acid required for re-titration	37·4 c.c.

216. 100 volumes of Manchester cannel gas contained 4·98 volumes of olefines, which yielded on combustion 13·93 volumes of carbon dioxide. Required the volumes of ethylene (C_2H_4) and butylene (C_4H_8) contained in the gas, and the value of the illuminating power of the gas expressed in percentages of ethylene.

CALCULATION OF THE RESULTS OF ATOMIC WEIGHT DETERMINATIONS.

The data required for these calculations, when not otherwise given, may be obtained from Table I. in the Appendix.

217. DUMAS found, on heating copper oxide in a stream of dry hydrogen, that a certain weight of this substance lost 59·789 grams of oxygen, and yielded 67·282 grams of water. Calculate from these numbers the atomic weight of hydrogen.

218. Marignac obtained 314·894 grams of silver nitrate from 200 grams of silver. 14·110 grams of silver nitrate required 6·191 grams of potassium chloride for complete precipitation, and 10·339 grams of silver dissolved in nitric acid required 5·120 grams of ammonium chloride for precipitation. Calculate the atomic weight of nitrogen from these data.

219. Stas found that 91·462 grams of metallic silver, when heated in a stream of chlorine, yielded 121·4993 grams of pure silver chloride. Calculate from this the atomic weight of chlorine.

220. Stas found, after adding 7·25682 grams of potassium chloride to 10·51995 grams of silver dissolved in nitric acid, that 0·0194 grams of silver remained in solution. Calculate from these data the atomic weight of potassium.

221. Erdmann and Marchand obtained 109·6308 grams of mercury from 118·3938 grams of the red oxide. Calculate the atomic weight of mercury.

222. Calculate the atomic weight of carbon from each of the following analyses by Redtenbacher and Liebig of

			Salt.		Silver.
1.	Silveracetate	$C_2H_3AgO_2$	28·803	grams gave	18·612
2:	Silvertartrate	$C_4H_4Ag_2O_6$	16·220	„ „	9·6175
3.	Silvermalate	$C_4H_4Ag_2O_5$	25·898	„ „	16·059

223. Mallet found that 8·2144 grams of ammonia-alum dried by exposure to air at 21°—25° C. yielded 0·9258 gram of Al_2O_3. Taking the following atomic weights: O = 15·961; S = 31·966; N = 14·010; find the atomic weight of aluminium.

224. Mallet found that 6·9617 grams $Al\,Br_3$ required 8·4429 grams of Ag for precipitation of the bromine; if Ag = 107·649 and Br = 79·754 what is the atomic weight of Al as deduced from this result?

225. 0·3697 gram of aluminium liberated 0·04106 gram of hydrogen on being dissolved in a strong solution of sodium hydrate; find atomic weight of aluminium.

226. A determination of the atomic weight of titanium was made by finding the weight of pure silver required to precipitate the chlorine from an aqueous solution in which a bulb containing a known weight of $TiCl_4$ had been broken. A quantity of the pure silver nearly sufficient was in each experiment first converted into nitrate and then mixed with the titanium solution, the precipitation was finished by addition from a burette of a centinormal

solution of $AgNO_3$. Find the atomic weight of Ti from the annexed data in each case. (Take Ag = 6·7456, Cl = 2·21586, H = 0·06265, O = 1.)

Corrected weight of $TiCl_4$ used.	Weight of silver weighed out.	Weight of silver added from burette.
2·43275 grams.	5·49288 grams.	0·03509 gram.
5·42332 „	12·30669 „	0·01591 „
3·59601 „	8·15960 „	0·01501 „
3·31222 „	7·44102 „	0·08619 „
4·20093 „	9·52445 „	0·02234 „

227. A series of experiments made for the purpose of determining the atomic weight of gold consisted in finding the ratio existing between the quantities of KBr and metallic Au remaining on the decomposition of potassium bromo-aurate by heat.

Taking the equivalent of H, 0·06265, K, 2·44523, and Br 4·99634, when O = 1, calculate the atomic weight of gold from the following data :

Weight of Au.		*Weight of KBr.*
6·19001	:	3·73440.
4·76957	:	2·87715.
4·14050	:	2·49822.
3·60344	:	2·17440.
3·67963	:	2·21978.
4·57757	:	2·76195.
5·36659	:	3·23821.
5·16406	:	3·11533.

228. The atomic weight of silicon has been determined by estimating the amount of SiO_2 obtained on treatment of known weights of $SiBr_4$ with water.

From the following table of results, find the ratio Si : H, taking H = 0·06265, and Br = 4·99721, (O = 1).

Weight of $SiBr_4$ *in vacuo.*	*Weight of* SiO_2 *in vacuo.*
9·63007 grams.	1·67070 grams.
12·36099 „	2·14318 „
12·98336 „	2·25244 „
9·02269 „	1·56542 „
15·38426 „	2·66518 „

229. Taking the atomic weights of O = 15·96, N = 14·02, H = 1, find the mean atomic weight of chromium from the given experimental results.

Corrected weight of $(NH_4)_2Cr_2O_7$.	*Corrected weight of* Cr_2O_3 *obtained therefrom.*
1·01275	0·61134
1·08181	0·65266
1·29430	0·78090
1·13966	0·68799
0·98778	0·59595
1·14319	0·68987

230. From the following readings given by Ramsay, showing the volume of hydrogen obtained by means of pure zinc, calculate the equivalent of zinc (H = 1).

Weight, in a vacuum, of the zinc used.	Reduced volume of hydrogen.	Reduced pressure.	Thermometer reading, C.
3·299584	1216·86 cc.	729·18 mm.	10·54
	1219·64 ,,	727·78 ,,	10·54
	1222·73 ,,	725·78 ,,	10·54
	1225·62 ,,	724·08 ,,	10·54
	1233·05 ,,	719·72 ,,	10·53
	1230·54 ,,	721·10 ,,	10·48
	1228·02 ,,	722·65 ,,	10·48

CALCULATIONS INVOLVED IN INDIRECT ANALYSIS.

There are three main types of Indirect Analysis, namely :—

(1) *The method of substitution;* an equivalent amount of some other radicle (or substance) is substituted for the radicle we wish to determine and is then estimated directly; for instance we may determine free Cl by adding to its solution KI when KCl is formed and free I, equivalent in amount to the Cl present, remains and can be estimated directly.

(2) *The residue method;* the body in which the radicle occurs undergoes a definite chemical change when acted upon by a known amount in excess of some reagent, and the excess of reagent is determined.

(3) *The method depending on the numerical differences between molecular weights;* with a mixture of two salts, differing considerably in molecular weight, but possessing a common constituent, it is possible from the estimation of the common radicle to calculate the quantities of each of the other radicles present in the mixture.

EXAMPLES.

(1) To 50 c.c. of a solution of Cl, an excess of potassium iodide solution was added; the liberated I was then estimated by means of a standard solution of $Na_2S_2O_3$ using starch solution to indicate the end of the reaction. 1 c.c. $Na_2S_2O_3$ solution = 0·0127 gram I, and 22·5 c.c. of this solution were used; what was the strength of the Cl solution in grams per c.c.?

$$\text{Iodine set free} = 0{\cdot}0127 \times 22{\cdot}5 \text{ gram.}$$

which is equivalent to $\dfrac{0{\cdot}0127 \times 22{\cdot}5 \times 35{\cdot}37}{126{\cdot}54}$ gram of Cl.

which was the weight of Cl contained in 50 c.c.

Hence, weight of Cl per c.c.

$$= \frac{0{\cdot}0127 \times 22{\cdot}5 \times 35{\cdot}37}{50 \times 126{\cdot}54} = 0{\cdot}001597 \text{ gram.}$$

(2). 0·2815 gram of calcite was dissolved in 30 c.c. of normal HNO_3, and the excess of acid determined by normal NaOH of which 24·43 c.c. were required; what percentage of CO_2 did the sample contain?

The HNO_3 neutralized by the $CaCO_3$ present in the calcite was 30·00 − 24·43 = 5·57 c.c.

126 grams HNO_3 are equivalent to 44 grams CO_2.

Hence, amount of CO_2 present was :—

$$\frac{0{\cdot}063 \times 5{\cdot}57 \times 44}{126} \text{ gram.}$$

and hence % of $CO_2 = \dfrac{0{\cdot}063 \times 5{\cdot}57 \times 44 \times 100}{126 \times 0{\cdot}2815} = 43{\cdot}53.$

(3). Two grams of a mixture of barium carbonate and calcium carbonate evolve 0·67 gram of carbon dioxide; find the percentages of Ca and Ba present in the mixture.

Taking the following atomic weights,—Ca, 40·0; Ba, 137·2; C. 12·0; O. 16; we have

$BaCO_3$ contains $\dfrac{44}{197{\cdot}2}$ of its weight of CO_2, and $CaCO_3$ contains $\dfrac{44}{100}$ of its weight of CO_2.

Let x be the weight of $BaCO_3$ in the mixture taken, then $(2 - x)$ is the weight of $CaCO_3$ present.

$$CO_2 \text{ present is } \frac{44}{197{\cdot}2}x + \frac{44}{100}(2 - x) = 0{\cdot}67.$$

$$\text{hence, } \frac{44\,(197{\cdot}2 - 100)}{100 \times 197{\cdot}2} \cdot x = 0{\cdot}21.$$

$$\therefore x = 0{\cdot}968 \text{ gm. } BaCO_3.$$

$$\text{and } 2 - x = 2 - 0{\cdot}968 = 1{\cdot}032 \text{ gm. } CaCO_3.$$

Whence % of Ba in mixture $= \dfrac{0{\cdot}968 \times 137{\cdot}2 \times 100}{197{\cdot}2 \times 2} = 33{\cdot}67.$

and % of Ca $= \dfrac{1{\cdot}032 \times 40 \times 100}{100 \times 2} = 20{\cdot}64.$

QUESTIONS.

231. 0·2151 gram of uric acid was heated with soda-lime and the evolved NH_3 absorbed in HCl. The NH_4Cl was evaporated to dryness and redissolved, the Cl being then thrown down as AgCl, of which 0·7390 gram was obtained; what percentage of nitrogen did the sample of uric acid contain?

232. 25 c.c. of a solution, containing 0·2105 gram of a copper alloy in the form of sulphates, was neutralized with Na_2CO_3 and then rendered acid by acetic acid; to the acidulated solution an excess of freshly prepared potassium iodide solution was added and the liberated iodine titrated by a standard $Na_2S_2O_3$ solution; 31·29 c.c. were required for the reaction. 25·22 c.c. of the thiosulphate solution were found to be equivalent to 25 c.c. of iodine solution of which 1 c.c. = 0·006313 gram of copper. Calculate the percentage amount of copper present in the alloy.

233. 0·5005 gram of a sample of calcite, was weighed out, dissolved in dilute HCl and precipitated as calcium oxalate; the washed precipitate was treated with dilute sulphuric acid and the solution titrated with potassium permanganate solution of which 1 c.c. = 0·0056 gram of iron; 100·08 c.c. of the permanganate were decolorized. What was the percentage of calcium in the mineral?

234. In an estimation of nitrogen by the soda-lime method, 0·2102 gram of benzamide was taken and the evolved ammonia absorbed in $\frac{N}{2}$ sulphuric acid solution, 25 c.c. being taken; the residual acid required 21·517 c.c. of $\frac{N}{2}$ NaOH for neutralization. What was the percentage amount of nitrogen in the benzamide?

235. The subjoined data were obtained in an estimation of NH_3 in $(NH_4)_2SO_4$ by the method of distillation with soda-lime in the wet way.

Weight of ammonium sulphate taken = 0·3200 gram.

Amount of H_2SO_4 solution taken = 60 c.c.

1 c.c. of acid solution = 0·855 c.c. $\frac{\text{normal}}{2}$· NaOH sol.

41·7 c.c. of $\frac{N}{2}$ soda just neutralized the residual acid.

Calculate from these data the percentage amount of ammonia in ammonium sulphate.

236. One hundred cubic centimetres of a semi-normal solution of sodium carbonate were added to 100 c.c. of a neutral solution containing copper sulphate. After filtration, the residual Na_2CO_3 was determined by means of $\frac{N}{2}$ sulphuric acid, of which 27 c.c. were required. What weight of $Cu\,SO_4$ in grams was present in each litre of the solution?

237. The following results, obtained in an analysis of Rochelle salt, give sufficient data for the estimation of K and Na in the sample used; find the percentage of each of these elements present.

Weight of salt taken	0·7012 gram.
Weight of mixed alkaline chlorides . . .	0·3305 „
Weight of Ag Cl obtained	0·7129 „

✓ 238. From 0·9330 gram of a mixture of sodium chloride and iodide, 0·9066 gram of sodium sulphate is obtained. What weights of the sodium chloride and sodium iodide are there in the weight of mixture taken?

(Take Na = 23, S = 32, O = 16, Cl = 35·5 I, = 127.)

GENERAL ANALYTICAL QUESTIONS.

239. CALCULATE the formula of a salt containing sodium and chlorine which yielded the following numbers on analysis:—

(*a*) 0·1998 gram of the salt gave
0·4865 gram of silver chloride, and
0·0032 „ metallic silver.

(*b*) 0·9543 gram of the salt gave
1·1584 grams of sodium sulphate.

240. 0·3951 gram of a substance supposed to be arsenic pentoxide was dissolved in dilute ammonia, and precipitated as magnesium-ammonium-arseniate. After drying at 110° the precipitate weighed 0·6544 gram. Was the substance $As_2\,O_5$?

241. The mineral nontronite gave on analysis the following numbers. Calculate its formula.

1·4155	grams of the mineral	gave	0·5711	grams of silica.
		and	0·5157	„ ferric oxide.
		„	0·0380	„ lime.
1·1205	„	lost on drying	0·2311	„ water.

242. 100 grams of a mixture of potassium and sodium chlorides have furnished 164·1 grams of potassium-platinum chloride. What is the composition of the mixture?

243. Calculate the formula of thallium perchlorate from the following determination:—0·1831 gram of salt gave 0·2476 gram of the double chloride of platinum and thallium.

244. Calculate the percentage amount of chlorine contained in vanadyl trichloride of which 3·9490 grams added to 7·383 grams of silver dissolved in nitric acid required 3 cubic centimetres of centesimal HCl solution for complete precipitation according to Gay-Lussac's method.

!245. Two equal volumes of a liquid found to contain an oxygen compound of bromine were completely reduced with sulphurous acid, the excess of which was removed by boiling: in one portion the sulphuric acid formed was estimated as barium salt, and in the other the bromine was weighed as silver bromide. Analysis gave: weight of Ba SO_4 = 0·402 gram; weight of silver bromide, 0·3240 gram. Required the composition of the oxide of bromine.

246. 1·2185 grams of perchloric acid yielded 1·6785 grams of dry potassium salt: of this salt 0·9660 gram lost 0·444 gram on heating, and the residue required 0·744 gram of pure silver for complete precipitation. Required the percentage amount of acid contained in the quantity taken. (Roscoe.)

!247. Required the percentage of real acid contained in 1·483 grams of aqueous acetic acid, which evolved 0·427 gram of carbonic acid on adding it to bicarbonate of sodium.

248. 2·122 grams of aqueous formic acid required for neutralization 36·3 cubic centimetres of soda solution, of

which each cubic centimetre contained (0·9025 × 31) milligrams of soda. Required the percentage of pure acid contained in the liquid.

249. Calculate the volume of carbonic acid in 10,000 volumes of sea-air, from the following numbers, obtained by Pettenkofer's method :—

1 cubic centimetre of oxalic acid solution = 1 mgrm. CO_2.
50 cubic centimetres of baryta water = 55·18 cubic centimetres of oxalic acid solution.
Capacity of flask used, 4815 cubic centimetres. Temp. of air 13$^{\text{C.}}$·9. Bar. 753·1 mm.
50 cubic centimetres of baryta solution taken : of this 25 cubic centimetres after the experiment required 26·29 cubic centimetres of oxalic acid solution for neutralization.

250. The following numbers express the amount of the constituents in 1,000 grams of the water of the Irish Channel :—

1.	Chlorine	18·62650
2.	Bromine	·06133
3.	Sulphuric acid (SO_4) . .	2·59280
4.	Lime (total)	0·57512
5.	Calcium carbonate . . .	0·04754
6.	Magnesia	2·03233
7.	Potassium	0·39131
8.	Sodium	10·40200
9.	Ferric oxide	·00465
10.	Ammonia	·00011
11.	Nitric acid	·00156
	Total fixed constituents	33·83855

Calculate the composition of the saline matter of the water on the following assumption : That the sodium, potassium, and ammonium are combined with chlorine, the excess of chlorine being united to magnesium. The bromine and nitric acid are also to be united to the magnesium. The sulphuric acid exists in combination with lime, the excess being united to magnesia. The ferric oxide exists as ferrous carbonate.

! 251. Calculate the illuminating power of a gas flame burning 5 cubic feet per hour, expressed in candles burning 120 grains (7·79 grams) of sperm per hour, from the following data :—

Rate at which gas issues = 4·8 cubic feet per hour.

Consumption of standard candle in 10 minutes = 1·38 grams.

Readings on the photometer scale for each minute of observation :—

(1), 27. (2), 22·5. (3), 17. (4), 21. (5), 18. (6), 19. (7), 19. (8), 20. (9), 19. (10), 21.

252. 0·5637 grams of the barium salt of an organic acid, obtained by the action of carbonic acid on $C_6H_4BrC_2H_5$ in presence of sodium, lost, on drying at 120° C., 0·0430 gram of water, and gave 0·2733 gram barium sulphate. Required the formula of the salt.

! 253. 4·826 grams of a nitrogenous organic body yielded, after heating with soda-lime, 1·532 grams of the double chloride of platinum and ammonium. Required the percentage of nitrogen contained in the organic substance.

! 254. Required the percentage composition, observed and calculated vapour density, and formula of a body which gave the following analytical results :—

(*a*) 0·4245 gram yielded
0·5670 gram of carbonic acid, and
0·3025 „ water.

(*b*) 0·1810 gram yielded.
0·3855 gram of silver chloride, and
0·0165 „ metallic silver.

(*c*) Determination of vapour density according to Gay-Lussac's method :—

Weight of substance employed, 0·0893 gram.

Temperature of the air, 8° C. Height of barometer, 739 mm.

Temperature of vapour, 50° C. Volume, 46·2 cubic centimetres.

Difference of level, 140·5 mm. Coefficient of expansion of mercury = 0·0001815.

Coefficient of cubical expansion of glass, 0·0000262.

255. 1·5055 grams of a mixture of sodium and potassium chlorides gave 3·4222 grams of silver chloride. Calculate the relative amounts of the two chlorides.

256. 1·2060 grams of a mixture of sodium bromide and sodium chloride gave, on complete precipitation by silver nitrate, 2·6554 grams of mixed silver chloride and bromide, which, on reduction, yielded 1·8418 grams of metallic silver. Calculate the proportion of chloride and bromide.

SOLUTION OF GASES IN LIQUIDS.

GASES fall into two groups when considered in relation to their solubility in liquids :—

(1). Those gases completely expelled from the solvent by raising its temperature or reducing the pressure to which it is subjected.

(2) Other gases.

I. In group (1), the amount of gas absorbed depends upon :—

I. The nature of the gas and of the absorbing liquid.

II. The actual pressure of the gas considered.

Henry's Law :—The quantity of any gas absorbed by a given quantity of a liquid is proportional to the pressure.

III. The temperature. Volume absorbed decreases with the increase of temperature ; it may be expressed by means of an empirical formula of the form $V=a-bt+ct^2$, where a, b, c are constants for each gas and t is the temperature.

The absorption-coefficient of a gas is a number which expresses the ratio of the volume of the gas, measured at 0° C. and the pressure of absorption, absorbed by the liquid at the temperature of observation to the volume of the absorbing liquid. In a mixture of gases, each component behaves as if it alone were present under the partial pressure which is exerted by itself.

EXAMPLE.

It is required to calculate the absorption coefficient of nitrogen dissolved in water at 19° C. from the appended data (Bunsen).

I. *Observations before Absorption.*

Lower level of mercury in outer cylinder a = 423·6 mm.
Upper level of mercury in absorption tube . . . . b = 124·1 „
Height of barometer . . . . p = 746·9 „
Temperature of absorptiometer . . . t = 19·2° C.
Temperature of barometer . . . . . . T = 19·0° C.

II. *Observations after Absorption.*

Lower level of mercury in outer cylinder a_1 = 352·2 mm.
Upper level of mercury in absorption tube . . . . b_1 = 350·7 „
Water level in absorption tube . . . . . c_1 = 65·5 „
Water level in outer cylinder . . . . . d_1 = 8·0 „
Height of barometer . . . . p_1 = 746·3 „
Temperature of absorptiometer . . . . t_1 = 19·0° C.
Temperature of barometer . . . . . . T_1 = 18·9° C.

III. *Tabular Data.*

Volumes, according to the calibration table, of:—

Gas taken. mark b = 124·1 mm. . . . V = 34·90.
Tube above b_1 = 350·7 mm. . . . . 200·04.
Tube above c_1 = 65·5 mm., remaining gas. V_1 = 17·67.
Hence water used for absorption. . . . (h) = 182·37.
Coefficient of expansion of mercury for 1° C. . =0·00018.

The absorption coefficient $a = \frac{1}{h}\left(\frac{VP}{P_1} - V_1\right)$

P and P_1 being the pressures of the dry gas before and after absorption respectively, V and V_1 being the corresponding volumes of gas reduced to 0° C.

$P = p$ reduced to 0° C. — $(a - b)$ reduced to 0° C. − vapour pressure of water at 19·2° C.

$= (744{\cdot}4 - 298{\cdot}5 - 16{\cdot}6)$ mm. $= 429{\cdot}3$ mm.

$P_1 = p_1$ reduced to 0° C. — $(a_1 - b_1)$ reduced to 0° C. $+ \{(a_1 - b_1) + (c_1 - d_1)\}$ reduced to equivalent mercury column at 0° C. — vapour pressure of water at 19° C.

$= (743{\cdot}8 - 1{\cdot}5 + 4{\cdot}4 - 16{\cdot}3)$ mm. $= 730{\cdot}4$ mm.

$$V = v \cdot \frac{1}{(1 + 0{\cdot}00367 \cdot 19{\cdot}2)} = 34{\cdot}90 \cdot \frac{1}{1 + 0{\cdot}00367 \cdot 19{\cdot}2} = 32{\cdot}608.$$

$$V_1 = v_1 \cdot \frac{1}{(1 + 0{\cdot}00367 \cdot 19)} = 17{\cdot}67 \cdot \frac{1}{1 + 0{\cdot}00367 \cdot 19} = 16{\cdot}52.$$

$$\text{Hence } a = \frac{1}{182{\cdot}37}\left(\frac{32{\cdot}608 \times 429{\cdot}3}{730{\cdot}4} - 16{\cdot}52\right) = 0{\cdot}01448.$$

QUESTIONS.

257. The absorption coefficient of nitrogen dissolved in water is 0·0152 at 12·6° C.; what volume of the gas measured at 0° C. and 760 mm. pressure is absorbed by one litre of water at 12·6° C. at each of the pressures :—
1000 mm., 748·2 mm., 391 mm., and 14·3 mm. ?

258. What is the volume of nitrogen absorbed in each case in question 257, measured at the temperature and pressure of the experiment? What is the weight of the gas absorbed in each case?

259. The absorption coefficient of hydrogen dissolved in water is represented by the interpolation formula $a = 0{\cdot}0215286 - 0{\cdot}00019216t + 0{\cdot}0000017228t^2$: what quantities of the gas measured (*a*) under the experimental conditions, (*b*) under standard conditions,

will be given off on boiling 325 c.c. of the solution made by agitating water in hydrogen (*A*) at 10° C. and 750 mm., (*B*) at 14° C. and 767 mm., (*C*) at 18° C. and 732 mm.?

260. The coefficient of absorption of carbon dioxide in water is found to be $a = 1·7967 - 0·07761t + 0·0016424t^2$; find the coefficients for $t = 4·4°$ C., 8·4° C., 13·8° C., 16·6° C., 19·1° C., and 22·4° C.

261. The coefficient of absorption of hydrogen in alcohol is given by the interpolation formula $a = 0·06925 - 0·0001487t + 0·000001t^2$; find the values of the coefficient at 1°, 5°, 11·4°, 14·4°, and 19·9° C., and compare each value with the corresponding value of the coefficient for water as given in question 259.

262. Find an interpolation formula expressing the variation of the coefficient of absorption of carbonic oxide in water with alteration of temperature, the coefficients found by experiment being :—at 5·8°, 0·028636; at 8·6°, 0·027125; at 17·4°, 0·023854; at 18·4°, 0·023147; at 9°, 0·026855; and at 22°, 0·022907.

263. At 23° C. the absorption-coefficient of oxygen in water is 0·03402, that of nitrogen is given by the expression $a = 0·020346 - 0·00053887t + 0·000011156t^2$; what will be the percentage composition by volume of the gas mixture obtained by boiling water previously saturated with air at 23° C.? (Air :—N, 79·1; O, 20·9.)

264. A litre of water saturated with carbon dioxide at 4·4° C. and 748 mm. is shaken up with a litre of nitrogen at 23° C. and 760 mm.; the temperature of the whole being now 23° C., what is the composition of the gas remaining over the solution, *a* for nitrogen being taken as in question 263, and for CO_2 being equal to $1·7967 - 0·07761t + 0·0016424t^2$?

265. A mixture of hydrogen and carbon dioxide is agitated with 356·4 c.c. of water at 5·5° C., volume of gas before absorption reduced to 0° C. = 171·29 c.c. and pressure = 0·5368 m.; vol. of gas after absorption at 0° C = 119·61 c.c., and its pressure = 0·6809 m.; *a* for H = 0·0193, for CO_2 = 1·4199; what is the percentage composition of the original mixture?

SOLUBILITY OF SOLIDS IN LIQUIDS. MOLECULAR WEIGHT AND THE LOWERING OF THE FREEZING-POINT OF SOLUTIONS.

THE solubility of solids in liquids does not admit of being represented by any simple law; the alteration of the solubility with temperature may generally be expressed by an equation of the form $x = a + bt + ct^2 + dt^3$, where a, b, c, d are constants for each set of substances considered, and t is the temperature.

As these constants have only been determined in a few cases, the consideration of problems arising in connection therewith does not fall within the scope of this book.

It has been found that substances dissolved in any solvents which solidify at attainable temperatures cause a lowering of the freezing-point according to the following law:—

If the molecular weight (in terms of any unit) of any substance be dissolved in 100 times the molecular weight (in terms of the same unit) of any liquid, the freezing-point of the latter is lowered by an amount always very near to 0·63° C.

Let A be the coefficient of lowering of the temperature of solidification (lowering produced by one gram dissolved in 100 grams of solvent), M be the molecular weight of the dissolved compound, T be the molecular lowering of the freezing-point (that produced by the molecular weight in grams of the substance dissolved in 100 grams of the solvent); then $MA = T$, and $M = \frac{T}{A}$.

If P be the weight of the solvent, P' the weight of the dissolved body, K the lowering of the freezing-point given by experiment, we have

$$A = K . \frac{P}{P' \times 100}.$$

And hence $M = \dfrac{T(P' \times 100)}{PK}$

If M' be the molecular weight of the solvent employed, then $T = M' \times 0{\cdot}63$ very nearly, with the exception of the solvent water.

T has been determined by numerous experiments for the commoner solvents; its mean value for:

Acetic acid = (18·0 in a few cases), 38·6.
Formic acid = 27·7.
Benzene = 50·0.
Nitrobenzene = 70·7.
Water = { 18·5 (for organic substances, some salts of diad metals, all the feeble bases and acids). 37 (for alkaline and alkaline earthy salts, and all the strong acids and bases).

EXAMPLE.

The freezing-point of a sample of acetic acid was found to be 16·490° C.; taking 62·014 grams of this acid and adding thereto 0·2540 gram of pure propionic acid, the solidifying point of the mixture is found to be 16·277° C. What is the molecular weight of propionic acid?

The observed lowering of the freezing-point is

$$16{\cdot}490 - 16{\cdot}277 = 0{\cdot}213^\circ = K,$$

the weight of solvent $P = 62{\cdot}014$ gram, weight of dissolved body $P' = 0{\cdot}2540$ gram, and $T = 38{\cdot}6$ for acetic acid, hence

$$M = \frac{38{\cdot}6\,(0{\cdot}2540 \times 100)}{62{\cdot}014 \times 0{\cdot}213} = 74{\cdot}2.$$

(Calculated molecular weight of $C_2H_5COOH = 74$)

QUESTIONS.

266. If the molecular lowering of the freezing-point of acetic acid, 16·75° C., be 43 in the case of benzoic acid, what is the temperature of solidification of a 4 per cent. solution?

267. Plot out a curve showing the relation between concentration and K in the case of ethyl formate dissolved in acetic acid,

Percentage of Ethyl Formate.	*Observed K.*
0·1977.	0·101° C.
0·3971.	0·212° C.
0·5935.	0·315° C.
0·9692.	0·511° C.
1·3907.	0·758° C.,

and find the mean molecular weight of the ethyl formate as given by this series of experiments.

268. Find the coefficient of lowering of the freezing-point of acetic acid by ethyl formate from the data of the preceding question.

269. What percentage of methyl acetate has been added to a sample of acetic acid freezing originally at 16·52° C. and after addition of the ester at 15·619° C.?

270. By what amounts should the freezing-point of benzene be lowered in 5 per cent. solutions of each of the following bodies—toluene, xylene, and anthracene?

271. Taking 56·7 gram of acetic acid freezing at 16·52° C. and adding methyl acetate in successive quantities as follows: (1) 0·0725 gram, (2) 0·0970 gram, (3) 0·0821 gram, (4) 0·1192 gram, the freezing-points after each addition are observed to be (1) 16·452°C.,(2) 16·363°C., (3) 16·282° C., and (4) 16·177° C. respectively; what is the molecular weight of methyl acetate found from each observation?

272. What should be the normal molecular lowering of the freezing-point in the case of (*a*) anthracene, (*b*) sodium, (*c*) tin?

273. 6 grams of anhydrous magnesium sulphate are dissolved in 100 grams of water; the observed depression of the freezing-point is 0·958° C. Taking the value of T to be 37, which of the following formulæ most probably represents the state of the dissolved salt, (*a*) $MgSO_4$: (*b*) $MgSO_4, 7H_2O$?

274. It has been found that the latent heat of fusion of a solvent is connected with the molecular lowering of its freezing-point as shown in the formula,

$$T = 0{\cdot}02.\ \frac{(\text{absolute temperature})^2}{\text{latent heat of fusion}}.$$

The freezing-point of ethylene dibromide being 7·9° C., and the molecular depression of its freezing-point 117·9, find its latent heat of fusion.

275. The value of T for water is 18·5, for formic acid 27·7, and for acetic acid 38·6, when organic substances are dissolved in each solvent. What inference may be drawn as to the relative complexity of the molecules of each of these solvents?

276. What conclusion would you draw as to the molecular weight of nitrogen tetroxide from the following data?

(*a*) 0·5269 gram of $CHCl_3$ introduced into 17·3046 grams of nitrogen tetroxide lowers the freezing-point of the latter by 1·06°.

(*b*) Similarly 0·4931 gram of C_6H_5Cl mixed with 16·7650 grams of nitrogen tetroxide lowers its freezing-point 1·09°.

277. Find the molecular weight of gold, from the figures below showing the effect of Au in lowering the freezing-point of Na. (Take T = 104).

Weights of Na.	Weights of Au added in succession.	Freezing-point.
20·425	—	97·44
(*a*) ,,	2·1	91·99
(*b*) ,,	1·316	88·59

278. Plot out a curve to show the variation of the molecular lowering of the freezing-point with concentration, using the data obtained by Haycock for mercury dissolved in sodium.

Weight of Na.	Weights of Hg added in succession.	Freezing.point.
32·47	—	97·47
”	0·5605	96·6
”	0·7410	95·38
”	0·5740	94·46
”	0·5170	93·64
”	1·771	90·93
”	4·950	83·35

EXERCISES ON THE SPECIFIC HEAT, LATENT HEAT, AND ATOMIC HEAT OF SUBSTANCES.

THE capacity of a body for heat is measured by determining the number of units of heat required to raise that body one degree of temperature.

The *Specific Heat* of a body is the ratio of the quantity of heat required to raise that body one degree to the quantity required to raise an equal weight of water one degree.

Latent Heat is the quantity of heat which must be communicated to a body in a given state in order to convert it into another state without changing its temperature.

The *Atomic Heat* of an element is the product of its atomic weight into its specific heat; for the greater number of the elements, the mean value of this quantity is 6·40. This is expressed by Dulong and Petit in the form of a law, thus:—The atoms of all elementary bodies have exactly the same capacity for heat.

The following table by Regnault shows the specific heat of the more important elements and compound gases between 0°—100° C.

Iron	0·11379	Sulphur	0·20259
Zinc	0·09555	Selenium	0·08370
Copper	0·09515	Tellurium	0·05155
Mercury	0·03332	Potassium	0·16956
„ (solid)	0·03241	Bromine (liquid)	0·11094
Cadmium	0·05669	„ (solid—28^{c})	0·08432
Silver	0·05701	Iodine	0·05412
Arsenic	0·08140	Carbon	0·24111
Lead	0·03140	Phosphorus	0·18870
Bismuth	0·03084	Atmospheric Air	0·2375
Antimony	0·05077	Oxygen	0·2175
Tin	0·05623	Nitrogen	0·2438
Nickel	0·10863	Hydrogen	3·4090
Cobalt	0·10696	Carbon monoxide	0·2479
Platinum plate	0·03243	Chlorine	0·1214
„ sponge	0·03293	Carbon dioxide	0·2164
Palladium	0·05927	Nitric oxide	0·2238
Gold	0·03244	Steam	0·475

The following table, embodying the results obtained by Person, gives the latent heat of several bodies :—

Water	79·25	Bismuth	12·64
Phosphorus	5·03	Lead	5·37
Sulphur	9·37	Zinc	28·13
Sodium nitrate	62·97	Mercury	2·83
Potassium nitrate	47·37	Steam	537
Sodium chloride	40·70	Alcohol vapour	208
Tin	14·25	Ether vapour	90

The heat required to raise the temperature of a kilogram of water through 1° C. is able to do work equivalent to the lifting of a kilogram weight through 425 metres. The *mechanical equivalent of heat* is 425 metre-kilograms.

A kilogram of water falling through a height of 425 metres, and having its motion suddenly arrested, would have its temperature raised 1° C.

QUESTIONS.

279. The following quantities of water are mixed together :—

1 kilogram at 40° C.
2 kilograms ” 30° ”
3 ” ” 20° ”
4 ” ” 5° ”

Calculate the temperature of the mixture.

! 280. If one kilogram of mercury at 20° C. be mixed with one kilogram of water at 0°, the temperature of the mixture will be 0·634° C. Calculate the specific heat of mercury.

! 281. Determine the specific heat of mercury from the observation that when the same vessel is filled successively with water and mercury, and heated to the same temperature, the water and mercury cool through the same number of degrees in 10 minutes and 270 seconds respectively. The specific gravity of mercury being considered constantly at 13·6.

282. Calculate the specific heat of mercury from the following numbers obtained by Kopp, according to his method :—

Temperature of mercury bath . .	51°·1	C.
Initial temperature in calorimeter .	13°·41	”
Final ” ” .	16°·50	”
Weight of water in calorimeter . .	26·945	grams.
Weight of mercury used	53·015	”
Thermal value of apparatus . . .	0·651	”

283. Calculate the specific heat of phosphorus from the following determination by Kopp :—

Temperature of mercury bath . .	38°·8	C.
Initial temperature in calorimeter .	10°·05	”
Final ” ” .	13°·20	grams.
Weight of water in calorimeter . .	26·95	”
Weight of phosphorus employed .	3·075	”
Weight of water in tube	2·065	”

† 284. The specific heat of water is 4 times, and its density 770 times, that of air. Supposing a cubic mile of water to yield up one degree of its heat to a cold atmosphere, what quantity would 1000 cubic miles of the atmosphere be heated?

285. A bar of platinum weighing 150 grams is heated in a furnace until its temperature becomes constant, when it is thrown into a kilogram of water, the temperature of which it raises from 15° to 20°. Required the temperature of the furnace on the assumption that the specific heat of platinum is $0·03308 + 0·0000042t$ between 0° and t°. (Pouillet.)

286. A determination of the specific heat of iron made in the calorimeter of Lavoisier and Laplace yielded the following data. Calculate the specific heat of iron :—

Weight of iron taken . . .	100 grams.
Weight of ice melted . . .	14·35 „
Initial temperature of iron .	100° C.
Latent heat of water . . .	79·25

287. The mechanical equivalent of heat is 425 metre-kilograms. What is this in foot-pounds?

288. From what height must a block of ice at 0° C. fall that the heat generated by its collision with the earth shall be just competent to melt it? From what height must it fall that the heat generated may be sufficient to convert it into steam?

289. If W_w = the number of scale divisions on a Bunsen's calorimeter equivalent to one gramme-degree unit of heat, T = the observed movement of the thread in scale divisions, G = the weight of substance taken and t its temperature, then sp. ht. $= \frac{T}{W_w . G . t}$. Find the sp. ht. of indium if $G = 1·1514$, $t = 99·82°$ C., $W_w = 14·657$ and $T = 100·2$. Time correction for $T = -3·45$.)

290. From the data given, find the specific heats of (*A*) cast silver, (*B*) cast zinc, (*C*) cast antimony, (*D*)

cast cadmium, (*E*) roll sulphur, as determined by Bunsen's method. $W_w = 14\cdot657$.

	A.	B.	C.	D.	E.
Weight of substance . .	3·6320	2·5150	3·8575	1·8675	1·0708
Temperature	100°C.	99·8°C.	99·8°C.	99·8°C.	100°C.
Scale movement	297·7	343·8	279·5	146·7	268·8

291. One kilogram of steam at 100° C. is condensed in forty-nine kilos of water at 16° C.; what is the temperature of the mixture?

292. It is required to distil 2 kilos. of ethyl alcohol (BP. 78·3°) per hour. What must be the supply of water at 16° C. in order that the temperature of the water round the worm may not average higher than 25° C.? (Specific heat of ethyl alcohol = 0·615).

293. 75 grams of water are placed in a calorimeter of which the water equivalent is 5 grams; when at 15° C., 5 grams of steam are passed into and condensed by the water with the result that the temperature of the calorimeter and its contents is raised to 51·6° C.; from these data calculate the latent heat of vaporization of steam.

294. Using the atomic weights given in Appendix I., calculate the atomic heats of Pb, Ag, Cu, Fe, S, and P.

295. Taking the mean value of the atomic heats of the elements as 6·4, and the specific heats given in the table, find the atomic weights of Ag, Zn, Bi, Sn, and Fe. The stochiometrical quantities of these elements found by analysis as equivalent to 35·37 parts of Cl are as follows:— Ag 107·66, Zn 32·44, Bi 69·16, Sn 29·339, and Fe 18·626; from these numbers deduce the exact atomic weights of the elements in question.

296. It is found that in many compounds the sum of the atomic heats of the atoms of which the molecule is built up equals the product of the molecular weight into the specific heat of the compound (the molecular heat); assuming this to be always the case, deduce the atomic heats in the solid state of Cl and O, from the data that the

sp. ht. of $PbCl_2$ = 0·0644 (Regnault), of Ga_2O_3 = 0·1062, and of In_2O_3 = 0·0807.

(Specific heats,—Ga, 0·079; In, 0·057.)

297. Deduce the atomic heat of oxygen from the molecular heat 28·3 of potassium permanganate.

(Specific heats,—K, 0·166; Mn, 0·122.)

298. Find the approximate atomic heat of hydrogen if the molecular heat of NH_4Cl be taken as 20, and the atomic heats of N and Cl as 5·6 and 6·4 respectively.

299. The atomic heat of lead is deduced from Regnault's value for the specific heat to be about 6·3, the specific heat of cerussite = 0·080, of calc-spar = 0·206, of strontianite = 0·145, and of witherite = 0·109; find the atomic heats of Ca, Sr, and Ba.

HEAT OF SOLUTION; HEAT OF COMBINATION; CALORIFIC POWER; CALORIFIC INTENSITY.

CHEMICAL change is usually accompanied by changes in the distribution of energy in the system considered. By far the larger part of the energy lost to the changing systems during chemical reactions is given out in the form of heat; reactions in which heat is evolved are said to be *exothermic*. There exists also a class of reactions requiring heat to be imparted from without the system to the reacting bodies to enable the change to occur; such reactions are termed *endothermic*.

It is convenient to consider the thermal effects of the solution of substances together with the changes of energy-distribution due to strictly chemical reactions. The thermal unit in general use in connection with problems of this character is defined to be the amount of heat required to raise the temperature of one kilogram of water one degree Centigrade (the Calorie).

Generally the heat of combination is only one of a number of factors in the total thermal effect, heat being absorbed in the liquefaction or vaporization and evolved on the solidification of the reacting substances and products.

In the phenomena of ordinary combustion the terms *calorific power* and *calorific intensity* are used; by the former we understand the amount of heat produced by the combustion of one unit of weight of the burning substance, whereas the latter indicates the temperature to which the products of combustion can be raised by the heat evolved.

The calorific intensity $I = \dfrac{H}{m_1s_1 + m_2s_2 + m_3s_3 + \ldots .}$ where H represents the calorific power, s_1 s_2 s_3 &c., the specific heats, and m_1 m_2 m_3 &c., the masses of the products of the combustion of one unit weight of substance.

The following table expresses the calorific powers of a number of substances burnt in oxygen :—

Hydrogen .	34,462.	Tin.	1,144.
Carbon . .	8,080.	Copper . . .	602.
Sulphur . .	2,220.	Carbonic oxide.	2,403.
Phosphorus .	5,747.	Marsh gas . .	13,063.
Zinc . . .	1,301.	Olefiant gas . .	11,858.
Iron . . .	1,576.	Alcohol . . .	6,850.

The calorific power of any substance is a constant, being the same whether the body be burnt in oxygen or in air and whether it be burnt rapidly or slowly; the calorific intensity is modified by the circumstances under which the combustion takes place, any mixture of inert material—*e.g.* nitrogen in air, ash in coal—lessening I since heat must be used to raise the temperature of the foreign matters. Again, if radiation be allowed to take place freely the temperature reached during slow combustion will not be nearly so high as that attained by a more rapid burning.

A special form of notation is used in thermo-chemistry—e.g. $[H^2, Cl^2] = 44,000 +$. in words means 'two kilograms of hydrogen combine with seventy-one kilograms of chlorine with the evolution (+) of 44,000 Calories.'

EXAMPLES.

1. The calorific power of carbon is 8080, what is its calorific intensity when burnt in oxygen?

12 parts of carbon give on combustion 44 parts of carbon dioxide, hence 1 kilo. produces 3·67 kilos. The specific heat of carbon dioxide is 0·2164.

$$\text{Hence } I = \frac{8080}{3\cdot67 \times 0\cdot2164} = 10{,}174^\circ\text{C}.$$

2. Find the calorific intensity of hydrogen burning in oxygen from the appended data.

Calorific power of hydrogen 34,462.

Weight of the product of combustion (H_2O) yielded by 1 kilo. of hydrogen, 9 kilos.

Specific heat of steam 0·475.

Here it must be remembered that at the temperature of combustion the water produced remains in the gaseous state, whereas the calorific power given above includes the heat given out on the condensation of the water vapour produced to water; hence the latent heat of vaporization of the water must be deducted from the given calorific power in calculating the value for *I*.

Assuming that the initial temperature is 0°C. the total heat required to raise the temperature of the water produced to $T^c = 9\left\{100 + 537 + 0\cdot475\,(T - 100)\right\}$ and this is necessarily the same as the calorific power. Hence $I = T^\circ$, and

$$9\left\{100 + 537 - 47\cdot5 + 0\cdot475\,T\right\} = 34{,}462.$$

$$589\cdot5 + 0\cdot475\,T = \frac{34462}{9}$$

$$\text{therefore} \quad I = T = \frac{\left(\frac{34462}{9} - 589\cdot5\right)}{0\cdot475} = 6820\cdot2^\circ\text{C}.$$

3. Determine the heat of formation of CH_2O_2 from its elements from the data:—

$[C,O^2] = 96{,}960 +$; $[H^2,O] = 68{,}360 +$; $[CH^2O^2,O] = 65{,}900 +$.

The total heat produced by the oxidation of free C. and H_2 to CO_2 and H_2O must evidently be equivalent to the heat of formation of CH_2O_2 together with the heat produced by the oxidation of CH_2O_2, for we obtain the same final products in both cases.

$[C,O^2] + [H^2,O] = [C,H^2,O^2] + [CH^2O^2,O]$. and $[C,O^2] +]H^2,O] = 96,960 + 68,360 = 165,320 +$.

$$\begin{aligned} \therefore\ [C,H^2,O^2] &= 165,320 - [CH^2O^2,O] \\ &= 165,320 - 65,900 \\ &= 99,420 + . \end{aligned}$$

4. Find the heat of solution of HBr from the data :—

(1) [KOH Aq, HCl Aq] = [KOH Aq, HBr Aq].

(2) [K Br Aq, Cl] = 11,500 +. (3) [Br, Aq] = 500 +.

(4) [H, Br] = 8,400. (5) [H, Cl, Aq] = 39,300.

From (2). [KBr Aq, Cl] = [K, Cl, Aq] + [Br, Aq] − [K, Br, Aq] = 11,500.

Replacement of Br by Cl gives 11500 thermal units. From this (5) and (1) we have

$$[H, Br, Aq] = [H, Cl, Aq] = 11,000 = 28,300$$

$$\text{and } [HBr, Aq] = [H, Br, Aq] - [H, Br]$$

$$\text{that is } [HBr, Aq] = 28,300 - 8,400 = 19,900,$$

or the heat of solution of HBr is represented by 19,900 thermal units.

QUESTIONS.

300. What weight of water would be heated from 0° to 1° C. by the combustion of 1 gram of hydrogen?

301. One gram of phosphorus is burnt in oxygen. To what temperature would a kilogram of water at 0° C. be raised by the combustion?

302. Calculate the amount of water raised 15° by the combustion of 1 gram of sulphur in oxygen.

303. Calculate the calorific intensity of (1) ethylene, (2) of methane burning in air.

304. Calculate the calorific intensity of Newcastle Hartley coal possessing the following percentage composition :—

Carbon	88·42
Hydrogen	5·61
Oxygen	5·97
	100·00

305. Determine the amount of heat disengaged by the combination of 1 gram of carbon with oxygen from the following experiment by Andrews :—

Weight of substance burnt . . .	1·088 grams.
Temperature of the air	10°·06 C.
The excess of the final temperature of the water above that of the air	0°·3 „
Increment of temperature found .	2°·473 „
„ „ corrected .	2°·464 „
Weight of water in the calorimeter	318·3 grams.
Thermal value of the vessels . .	180 „

! 306. Calculate the thermal power of charcoal from the following data :—

Weight of substance consumed .	10 parts.
„ the water	8900 „
„ the copper vessel . .	1000 „
Specific heat of copper	0·09515
Initial temperature	11° C.
Final „	20° C.

307. Calculate the height to which a ton weight would be raised by the combustion of a kilogram of this charcoal, supposing that all the heat evolved was utilised in the lifting.

308. Find the heat of formation of H_2SO_4 from its elements.

Data given :—$[H^2SO^3Aq, H^2O, Cl^2] = 73{,}900$;
$[H, Cl, Aq] = 39{,}300$; $[H^2,O] = 68{,}400$;
$[SO^2,Aq] = 7{,}700$; $[S,O^2] = 69{,}900$; $[SO^3,Aq] = 37{,}400$;
$[H^2SO^4, Aq] = 17{,}000$:

309. Given that $[C,O^2] = 96,900$ and $[H^2,O] = 68,400$, find the heat of formation of CH_4, if the complete combustion of CH_4 gives 213,500 heat units.

310. From the given data, find the heat of formation of

HCN :—$[C,O^2] = 96,900$; $[H^2,O] = 68,400$;
$[2HCN,5O] = 319,000$.

311. What is the thermal value of the reaction $[N^2,O]$? Data :—$[C,2N^2O] = 133,900$. $[C,O^2] = 96,900$.

312. Calculate the heat of combination of alcohol and acetic acid $[C^2H^6O, C^2H^4O^2]$, having given :—

$[C^2H^6O,O^6] = 330,400$; $[C^2H^4O^2,O^4] = 210,300$;
$[(C^2H^5)OOC.CH^3, 5.O^2] = 553,780$.

313. Find the heat of formation of aldehyde from its elements, (*a*) liquid, (*b*) gaseous.

Data :—$C_2H_4O + 5.O = 2CO_2 + 2H_2O$.
$[C^2H^4O, 5O] = 275,500$; $[C,O^2] = 96,900$;
$[H^2,O]$ liquid $= 68,400$; $[H^2,O]$ gaseous $= 58,700$;
$[C^2H^4O,5O]$ gaseous $= 266,000$.

314. The heat of solution of K_2SO_4 is 6340 –, of $CuSO_4,5H_2O$ is 2430 –, of $K_2SO_4.CuSO_4.7H_2O = 14,360$ –. What is the heat of formation of the double salt in solution?

315. $[P^2,O^5] = 369,100 +$ with ordinary phosphorus, $[P^2,O^5] = 326,800 +$ with amorphous phosphorus. What is the thermal value of the change from the yellow to the red variety?

316. In the reaction $[H^3PO^3Aq, x\ NaOH\ Aq]$ the heat of neutralization for $x = \frac{1}{2}$ is 7,400; for $x = 1$ is 14,800; for $x = 2$ is 28,500; for $x = 3$ is 28,900. What deductions may be drawn as to the basicity of this acid?

Questions marked thus (!) are from the Owens College Calendars. Questions marked thus (†) are from the examination papers of the Science and Art Department.

APPENDIX.

TABLE I.

Atomic Weights and Symbols of the Elements.

Elements.	Symbol.	Atomic Weight.	Observer.
Aluminium	Al.	27·04	Mallet.
Antimony	Sb (Stibium)	119·6	Cooke.
Arsenic	As.	74·9	Berzelius.
Barium	Ba.	136·86	Pelouze; Marignac.
Beryllium	Be.	9·08	Nilson & Pettersson.
Bismuth	Bi.	207·5	Schneider; (208·38: Classen).
Boron	B.	10·9	Deville.
Bromine	Br.	79·76	Stas.
Cadmium	Cd.	111·7	Lenssen.
Cæsium	Cs.	132·7	Johnson & Allen.
Calcium	Ca.	39·91	Erdmann & Marchand.
Carbon	C.	11·97	Van der Plaats.
Cerium	Ce.	139·90	Robinson.
Chlorine	Cl.	35·37	Stas.
Chromium	Cr.	52·06	Rawson.
Cobalt	Co.	58·6	Russell.
Copper	Cu (Cuprum)	63·18	Hampe; (63·45: Richards).
Didymium	Di.	146·0	Brauner.
Erbium	E.	166	Cleve.
Fluorine	F.	19·06	Louyet.
Gallium	Ga.	69·9	Lecoq de Boisbaudran.
Germanium	Ge.	72·3	Winkler.
Gold	Au (Aurum)	196·85	Thorpe & Laurie.
Hydrogen	H.	1	
Indium	In.	113·4	Winkler.
Iodine	I.	126·54	Stas.
Iridium	Ir.	192·5	Seubert.
Iron	Fe (Ferrum)	55·88	Berzelius; Erdmann & Marchand.

TABLE I.—(*continued.*)

Elements.	Symbol.	Atomic Weight.	Observer.
Lanthanum	La.	138·81	Marignac.
Lead	Pb (Plumbum)	206·39	Stas.
Lithium	Li.	7·01	Stas.
Magnesium	Mg.	23·94	Marchand & Scheerer.
Manganese	Mn.	54·8	Dumas; Dewar & Scott.
Mercury	Hg (Hydrargyrum)	199·8	Erdmann & Marchand.
Molybdenum	Mo.	95·89	Von der Pfordten.
Nickel	Ni.	58·6	Russell.
Niobium	Nb.	93·7	Marignac.
Nitrogen	N.	14·01	Stas.
Osmium	Os.	191·12	Seubert.
Oxygen	O.	15·96	Dumas; Erdmann & Marchand.
Palladium	Pd.	106·35	Keiser.
Phosphorus	P.	30·96	Schrötter.
Platinum	Pt.	194·3	Seubert.
Potassium	K (Kalium)	39·03	Stas.
Rhodium	Rh.	104·1	Berzelius.
Rubidium	Rb.	85·34	Heycock.
Ruthenium	Ru.	103·5	Claus.
? Samarium	Sm.	150	Cleve.
Scandium	Sc.	43·97	Nilson.
Selenium	Se.	78·87	Petterssön & Ekman.
Silicon	Si.	28·0	Dumas; Schiel; (28·33: Thorpe & Young.)
Silver	Ag (Argentium)	107·66	Stas.
Sodium	Na (Natrium)	22·99	Stas.
Strontium	Sr.	87·3	Dumas.
Sulphur	S.	31·98	Stas.
Tantalum	Ta.	182·0	Marignac.
Tellurium	Te.	125	Brauner.
Thallium	Tl.	203·7	Crookes.
Thorium	Th.	231·99	Krüss & Nilson.
Tin	Sn (Stannum)	117·35	Berzelius; (117·8: Van der Plaats).
Titanium	Ti.	48·0	Thorpe.
Tungsten	W (Wolfram)	183·6	Schneider; Marchand; Persoz.
Uranium	U.	238·9	Zimmermann, Alibegoff & Krüss.
Vanadium	V.	51·1	Roscoe.
Ytterbium	Yb.	172·8	Marignac.
Yttrium	Y.	88·9	Cleve.
Zinc	Zn.	64·88	Erdmann; (65·18: Van der Plaats).
Zirconium	Zr.	90·40	G. H. Bailey.

TABLE II.

Weight of one Cubic Centimetre of Atmospheric Air at different Temperatures from 0° to 300°, at 760 mm. pressure.

°		°		°		°	
0	0·001293	46	0·001108	92	0·000967	138	0·000858
1	001288	47	001105	93	000964	139	000856
2	001284	48	001102	94	000962	140	000854
3	001279	49	001098	95	000959	141	000852
4	001275	50	001095	96	000956	142	000850
5	001270	51	001091	97	000953	143	000848
6	001266	52	001088	98	000951	144	000846
7	001261	53	001084	99	000948	145	000844
8	001257	54	001081	100	000946	146	000842
9	001252	55	001077	101	000943	147	000840
10	001248	56	001074	102	000941	148	000838
11	001243	57	001070	103	000938	149	000836
12	001239	58	001067	104	000936	150	000834
13	001234	59	001063	105	000933	151	000832
14	001230	60	001060	106	000931	152	000830
15	001225	61	001057	107	000928	153	000828
16	001221	62	001053	108	000926	154	000826
17	001217	63	001050	109	000923	155	000824
18	001213	64	001047	110	000921	156	000822
19	001209	65	001044	111	000919	157	000821
20	001205	66	001041	112	000916	158	000819
21	001201	67	001038	113	000914	159	000817
22	001197	68	001035	114	000911	160	000815
23	001193	69	001032	115	000909	161	000813
24	001189	70	001029	116	000907	162	000811
25	001185	71	001026	117	000905	163	000809
26	001181	72	001023	118	000903	164	000807
27	001177	73	001020	119	000900	165	000806
28	001173	74	001017	120	000898	166	000804
29	001169	75	001014	121	000896	167	000802
30	001165	76	001011	122	000894	168	000800
31	001161	77	001008	123	000891	169	000798
32	001157	78	001005	124	000889	170	000796
33	001154	79	001002	125	000887	171	000794
34	001150	80	001000	126	000884	172	000793
35	001146	81	000997	127	000882	173	000791
36	001142	82	000994	128	000880	174	000789
37	001138	83	000992	129	000878	175	000788
38	001134	84	000989	130	000876	176	000786
39	001131	85	000986	131	000874	177	000784
40	001128	86	000983	132	000871	178	000782
41	001124	87	000980	133	000869	179	000781
42	001121	88	000977	134	000867	180	000779
43	001118	89	000974	135	000865	181	000777
44	001114	90	000972	136	000863	182	000776
45	001111	91	000969	137	000860	183	000774

TABLE II.—(*continued.*)

°		°		°		°	
184	0·000772	213	0·000725	242	0·000685	271	0·000648
185	000770	214	000724	243	000683	272	000647
186	000769	215	000722	244	000682	273	000646
187	000767	216	000721	245	000681	274	000645
188	000765	217	000719	246	000679	275	000643
189	000763	218	000718	247	000678	276	000642
190	000762	219	000716	248	000677	277	000641
191	000760	220	000715	249	000675	278	000640
192	000758	221	000713	250	000674	279	000639
193	000757	222	000712	251	000673	280	000638
194	000755	223	000710	252	000672	281	000636
195	000754	224	000709	253	000670	282	000635
196	000752	225	000708	254	000669	283	000634
197	000751	226	000706	255	000668	284	000633
198	000749	227	000705	256	000666	285	000631
199	000748	228	000703	257	000665	286	000630
200	000746	229	000702	258	000664	287	000629
201	000744	230	000701	259	000663	288	000628
202	000743	231	000699	260	000662	289	000627
203	000740	232	000698	261	000660	290	000626
204	000739	233	000697	262	000659	291	000625
205	000737	234	000695	263	000658	292	000624
206	000736	235	000694	264	000657	293	000623
207	000734	236	000692	265	000655	294	000622
208	000733	237	000691	266	000654	295	000621
209	000731	238	000690	267	000653	296	000620
210	000730	239	000689	268	000652	297	000619
211	000728	240	000688	269	000651	298	000618
212	000727	241	000686	270	000650	299	000617
						300	000616

TABLE III.

The weight of 1000 *c.c. of water of* t° C., *when determined by means of brass weights in air of* 0° *C., and of a tension* 0·76*m.*, *is equal to* 1000 – x *grms.*

t°	0	1	2	3	4	5	6	7	8	9	10	11	12
x	1·26	1·20	1·16	1·13	1·12	1·12	1·14	1·17	1·22	1·28	1·35	1·44	1·54
t°	13	14	15	16	17	18	19	20	21	22	23	24	25
x	1·65	1·78	1·92	2·07	2·23	2·40	2·58	2·78	2·99	3·20	3·43	3·66	3·90
t°	26	27	28	29	30								
x	4·17	4·45	4·72	4·99	5·26								

TABLE IV.

Volume and Density of Water at different Temperatures, (ROSSETTI).

Temp. °C.	Volume of Water (at 0° = 1).	Sp. Gr. of Water (at 0° = 1).	Volume of Water (at 4° = 1).	Sp. Gr. of Water (at 4° = 1).
0	1·00000	1·000000	1·00013	0·999871
1	0·99994	1·000057	1·00007	0·999928
2	0·99990	1·000098	1·00003	0·999969
3	0·99988	1·000120	1·00001	0·999991
4	0·99987	1·000129	1·00000	1·000000
5	0·99988	1·000119	1·00001	0·999990
6	0·99990	1·000099	1·00003	0·999970
7	0·99994	1·000062	1·00007	0·999933
8	0·99999	1·000015	1·00011	0·999886
9	1·00005	0·999953	1·00018	0·999824
10	1·00012	0·999876	1·00025	0·999747
11	1·00022	0·999784	1·00034	0·999655
12	1·00032	0·999678	1·00045	0·999549
13	1·00044	0·999559	1·00057	0·999430
14	1·00057	0·999429	1·00070	0·999299
15	1·00071	0·999289	1·00084	0·999160
16	1·00087	0·999131	1·00100	0·999002
17	1·00103	0·998970	1·00116	0·998841
18	1·00122	0·998782	1·00135	0·998654
19	1·00141	0·998588	1·00154	0·998460
20	1·00161	0·998388	1·00174	0·998259
21	1·00183	0·998176	1·00196	0·998047
22	1·00205	0·997956	1·00217	0·997828
23	1·00228	0·997730	1·00240	0·997601
24	1·00251	0·997495	1·00264	0·997367
25	1·00276	0·997249	1·00289	0·997120
26	1·00301	0·996994	1·00314	0·996866
27	1·00328	0·996732	1·00341	0·996603
28	1·00355	0·996460	1·00368	0·996331
29	1·00383	0·996179	1·00396	0·996051
30	1·00412	0·99589	1·00425	0·99577
40	1·00757	...	...	...
50	1·01182	...	...	...
60	1·01678	...	...	...
70	1·02243	...	...	...
80	1·02874	...	...	...
90	1·03554	...	...	...
100	1·04299	...	...	...

TABLE V

For the Calculation of $\frac{1}{1+0\cdot00367T}$.

T		T		T		T	
1	[illegible]	38	[illegible]	75	[illegible]	112	0·70870
2	[illegible]	39	[illegible]	76	[illegible]	113	70686
3	[illegible]	40	[illegible]	77	[illegible]	114	70503
4	[illegible]	41	[illegible]	78	[illegible]	115	70321
5	[illegible]	42	[illegible]	79	[illegible]	116	70140
6	[illegible]	43	[illegible]	80	[illegible]	117	69960
7	[illegible]	44	[illegible]	81	[illegible]	118	[illegible]
8	[illegible]	45	[illegible]	82	[illegible]	119	[illegible]
9	[illegible]	46	[illegible]	83	[illegible]	120	[illegible]
10	[illegible]	47	[illegible]	84	[illegible]	121	[illegible]
11	[illegible]	48	[illegible]	85	[illegible]	122	[illegible]
12	[illegible]	49	[illegible]	86	[illegible]	123	[illegible]
13	[illegible]	50	[illegible]	87	[illegible]	124	[illegible]
14	[illegible]	51	[illegible]	88	[illegible]	125	[illegible]
15	[illegible]	52	[illegible]	89	[illegible]	126	[illegible]
16	[illegible]	53	[illegible]	90	[illegible]	127	[illegible]
17	[illegible]	54	[illegible]	91	[illegible]	128	[illegible]
18	[illegible]	55	[illegible]	92	[illegible]	129	[illegible]
19	[illegible]	56	[illegible]	93	[illegible]	130	[illegible]
20	[illegible]	57	[illegible]	94	[illegible]	131	[illegible]
21	[illegible]	58	[illegible]	95	[illegible]	132	[illegible]
22	[illegible]	59	[illegible]	96	[illegible]	133	[illegible]
23	[illegible]	60	[illegible]	97	[illegible]	134	[illegible]
24	[illegible]	61	[illegible]	98	[illegible]	135	[illegible]
25	[illegible]	62	[illegible]	99	[illegible]	136	[illegible]
26	[illegible]	63	[illegible]	100	[illegible]	137	[illegible]
27	[illegible]	64	[illegible]	101	[illegible]	138	[illegible]
28	[illegible]	65	[illegible]	102	[illegible]	139	[illegible]
29	[illegible]	66	[illegible]	103	[illegible]	140	[illegible]
30	[illegible]	67	[illegible]	104	[illegible]	141	[illegible]
31	[illegible]	68	[illegible]	105	[illegible]	142	[illegible]
32	[illegible]	69	[illegible]	106	[illegible]	143	[illegible]
33	[illegible]	70	[illegible]	107	[illegible]	144	[illegible]
34	[illegible]	71	[illegible]	108	[illegible]	145	[illegible]
35	[illegible]	72	[illegible]	109	[illegible]	146	[illegible]
36	[illegible]	73	[illegible]	110	[illegible]	147	[illegible]
37	[illegible]	74	[illegible]	111	[illegible]	148	[illegible]

TABLE VI.

Pressure (*tension*) *of Water Vapour between* – 19° *and* 101° *C.*, (Broch).

T.°C.	mm.	T.°C.	mm.	T.°C.	mm.	T.°C.	mm.
– 19	1·0288	12	10·4322	43	64·3104	74	276·8675
– 18	1·1202	13	11·1370	44	67·7568	75	288·7640
– 17	1·2187	14	11·8835	45	71·3619	76	301·0860
– 16	1·3248	15	12·6739	46	75·1314	77	313·8475
– 15	1·4390	16	13·5103	47	79·0714	78	327·0549
– 14	1·5618	17	14·3950	48	83·1883	79	340·7265
– 13	1·6939	18	15·3304	49	87·4882	80	354·8730
– 12	1·8357	19	16·3189	50	91·9780	81	369·5075
– 11	1·9880	20	17·3632	51	96·6644	82	384·6432
– 10	2·1514	21	18·4659	52	101·5541	83	400·2933
– 9	2·3266	22	19·6297	53	106·6546	84	416·4721
– 8	2·5143	23	20·8576	54	111·9730	85	433·1938
– 7	2·7153	24	22·1524	55	117·5162	86	450·4730
– 6	2·9304	25	23·5174	56	123·2925	87	468·3240
– 5	3·1605	26	24·9556	57	129·3095	88	486·7635
– 4	3·4065	27	26·4705	58	135·5750	89	505·8059
– 3	3·6693	28	28·0654	59	142·0973	90	525·4676
– 2	3·9499	29	29·7439	60	148·8848	91	545·7650
– 1	4·2493	30	31·5096	61	155·9456	92	566·7149
0	4·5687	31	33·3664	62	163·2889	93	588·3349
+ 1	4·9091	32	35·3181	63	170·9236	94	610·6426
2	5·2719	33	37·3689	64	178·8585	95	633·6567
3	5·6582	34	39·5228	65	187·1028	96	657·3956
4	6·0693	35	41·7842	66	195·6663	97	681·8791
5	6·5067	36	44·1577	67	204·5586	98	707·1271
6	6·9718	37	46·6477	68	213·7895	99	733·1602
7	7·4660	38	49·2950	69	223·3691	100	760·0000
8	7·9909	39	51·9965	70	233·3079	101	787·6678
9	8·5484	40	54·8651	71	243·6163		
10	9·1398	41	57·8700	72	254·3048		
11	9·7671	42	61·0167	73	265·3849		

TABLE V.

For the Calculation of $\frac{1}{1 + 0{\cdot}00367T}$.

T		T		T		T	
1	0·99634	38	0·87761	75	0·78416	112	0·70870
2	99271	39	87479	76	78191	113	70686
3	98911	40	87199	77	77967	114	70503
4	98553	41	86921	78	77745	115	70321
5	98198	42	86645	79	77523	116	70140
6	97845	43	86370	80	77304	117	69960
7	97495	44	86097	81	77085	118	69781
8	97148	45	85826	82	76867	119	69603
9	96803	46	85556	83	76651	120	69425
10	96460	47	85289	84	76436	121	69249
11	96120	48	85022	85	76222	122	69073
12	95782	49	84758	86	76010	123	68899
13	95446	50	84495	87	75798	124	68725
14	95113	51	84234	88	75588	125	68552
15	94782	52	83974	89	75379	126	68380
16	94454	53	83716	90	75171	127	68209
17	94127	54	83460	91	74964	128	68038
18	93803	55	83205	92	74758	129	67869
19	93482	56	82952	93	74554	130	67700
20	93162	57	82700	94	74354	131	67532
21	92844	58	82450	95	74148	132	67365
22	92529	59	82201	96	73947	133	67199
23	92216	60	81954	97	73747	134	67034
24	91905	61	81708	98	73548	135	66870
25	91596	62	81464	99	73350	136	66706
26	91289	63	81221	100	73153	137	66543
27	90984	64	80979	101	72957	138	66380
28	90682	65	80740	102	72762	139	66219
29	90381	66	80501	103	72568	140	66059
30	90082	67	80264	104	72376	141	65899
31	89785	68	80028	105	72184	142	65740
32	89490	69	79794	106	71993	143	65582
33	89197	70	79561	107	71803	144	65424
34	88906	71	79329	108	71615	145	65268
35	88617	72	79099	109	71427	146	65112
36	88330	73	78870	110	71240	147	64957
37	88044	74	78642	111	71055	148	64802

TABLE VI.

Pressure (tension) of Water Vapour between – 19° *and* 101° *C.,* (BROCH).

T.°C.	mm.	T.°C.	mm.	T.°C.	mm.	T.°C.	mm.
–19	1·0288	12	10·4322	43	64·3104	74	276·8675
–18	1·1202	13	11·1370	44	67·7568	75	288·7640
–17	1·2187	14	11·8835	45	71·3619	76	301·0860
–16	1·3248	15	12·6739	46	75·1314	77	313·8475
–15	1·4390	16	13·5103	47	79·0714	78	327·0549
–14	1·5618	17	14·3950	48	83·1883	79	340·7265
–13	1·6939	18	15·3304	49	87·4882	80	354·8730
–12	1·8357	19	16·3189	50	91·9780	81	369·5075
–11	1·9880	20	17·3632	51	96·6644	82	384·6432
–10	2·1514	21	18·4659	52	101·5541	83	400·2933
–9	2·3266	22	19·6297	53	106·6546	84	416·4721
–8	2·5143	23	20·8576	54	111·9730	85	433·1938
–7	2·7153	24	22·1524	55	117·5162	86	450·4730
–6	2·9304	25	23·5174	56	123·2925	87	468·3240
–5	3·1605	26	24·9556	57	129·3095	88	486·7635
–4	3·4065	27	26·4705	58	135·5750	89	505·8059
–3	3·6693	28	28·0654	59	142·0973	90	525·4676
–2	3·9499	29	29·7439	60	148·8848	91	545·7650
–1	4·2493	30	31·5096	61	155·9456	92	566·7149
0	4·5687	31	33·3664	62	163·2889	93	588·3349
+1	4·9091	32	35·3181	63	170·9236	94	610·6426
2	5·2719	33	37·3689	64	178·8585	95	633·6567
3	5·6582	34	39·5228	65	187·1028	96	657·3956
4	6·0693	35	41·7842	66	195·6663	97	681·8791
5	6·5067	36	44·1577	67	204·5586	98	707·1271
6	6·9718	37	46·6477	68	213·7895	99	733·1602
7	7·4660	38	49·2950	69	223·3691	100	760·0000
8	7·9909	39	51·9965	70	233·3079	101	787·6678
9	8·5484	40	54·8651	71	243·6163		
10	9·1398	41	57·8700	72	254·3048		
11	9·7671	42	61·0167	73	265·3849		

TABLE VII.

For the Conversion of the Degrees (T′) *of a Mercurial Thermometer into the corresponding values* (T″) *of a Hydrogen Thermometer.*

T′	T″	T′	T″	T′	T″	T′	T″
−10°·07	−10°·00	100°	100	189·65	190	280·52	280
0·00	0·00	109·98	110	199·70	200	290·81	290
+10·05	+10°·00	119·95	120	209·75	210	301·08	300
20·08	20·00	129·91	130	219·80	220	311·45	310
30·10	30·00	139·85	140	229·85	230	321·80	320
40·11	40·00	149·80	150	239·90	240	332·40	330
50·10	50·00	159·74	160	250·05	250	343·00	340
60·09	60·00	169·68	170	260·20	260	354·00	350
70·07	70·00	179·63	180	270·38	270		
80·05	80·00						
90·03	90·00						

TABLE VIII.

For the Correction of Thermometer Readings.

$t-t'$	n									
	10	20	30	40	50	60	70	80	90	100
10	0·01	0·03	0·04	0·06	0·07	0·09	0·10	0·11	0·13	0·14
20	0·02	0·06	0·09	0·11	0·14	0·17	0·20	0·22	0·26	0·29
30	0·04	0·09	0·13	0·17	0·21	0·26	0·30	0·34	0·39	0·43
40	0·05	0·11	0·17	0·23	0·28	0·34	0·40	0·47	0·52	0·57
50	0·07	0·14	0·21	0·29	0·36	0·43	0·50	0·60	0·64	0·71
60	0·08	0·17	0·25	0·35	0·43	0·51	0·60	0·70	0·77	0·86
70	0·10	0·20	0·30	0·40	0·50	0·60	0·70	0·80	0·90	1·00
80	0·11	0·23	0·34	0·45	0·57	0·68	0·80	0·91	1·03	1·14
90	0·13	0·26	0·39	0·51	0·64	0·77	0·90	1·03	1·16	1·30
100	0·14	0·28	0·43	0·57	0·71	0·85	1·00	1·14	1·29	1·43
110	0·16	0·31	0·47	0·63	0·79	0·94	1·10	1·26	1·42	1·58
120	0·17	0·34	0·51	0·69	0·86	1·03	1·20	1·37	1·54	1·71

$t-t'$	n									
	110	120	130	140	150	160	170	180	190	200
10	0·16	0·17	0·19	0·20	0·21	0·22	0·24	0·26	0·27	0·29
20	0·31	0·34	0·37	0·40	0·43	0·46	0·49	0·51	0·54	0·57
30	0·47	0·51	0·56	0·60	0·64	0·68	0·73	0·77	0·82	0·86
40	0·63	0·69	0·74	0·80	0·86	0·91	0·97	1·03	1·09	1·14
50	0·79	0·86	0·93	1·00	1·07	1·14	1·22	1·29	1·36	1·43
60	0·94	1·03	1·12	1·20	1·29	1·37	1·46	1·54	1·63	1·72
70	1·10	1·20	1·30	1·40	1·50	1·60	1·70	1·80	1·90	2·00
80	1·26	1·37	1·49	1·60	1·72	1·83	1·94	2·05	2·17	2·29
90	1·42	1·54	1·66	1·80	1·93	2·05	2·17	2·31	2·45	2·54
100	1·58	1·71	1·84	2·00	2·15	2·29	2·43	2·57	2·72	2·86
110	1·73	1·89	2·04	2·20	2·36	2·51	2·67	2·83	2·99	3·15
120	1·89	2·06	2·23	2·40	2·57	2·74	2·92	3·09	3·26	3·43

TABLE IX.

Useful Constants.

	Number.	Logarithm.
π	3·1416	0·4971499
g, at Greenwich.	981·17 cms.	2·9917443
Coefficient of expansion of Hg. for 1° C. .	0·0001802	$\bar{4}$·2557548
Mass of 1 c.c. of Hg. at 0° C.	13·596 grams.	1·1334112
Volume of 31·92 gm. of oxygen in litres. .	22·325	1·3487915
Conventional molecular vol. in litres. . .	22·4	1·3502480
Coeff. exp. air, at constant pressure . . .	0·00367	$\bar{3}$·5646661
Coeff. elasticity of air at constant volume .	0·003665	$\bar{3}$·5640740
One litre of hydrogen at 0°C and 760 mm. barometric pressure and at the level of the sea and latitude 45° weighs . . .	0·08958 grms.	$\bar{2}$·9522111
Do. oxygen.	1·4298 ,,	0·1552753
Do. nitrogen	1·2562 ,,	0·0990588
Do. air	1·2932 ,,	0·1116657

TABLE X.—LOGARITHMS.

Proportional Parts.

Nat. numb.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10

LOGARITHMS.

Nat. numb.	0	1	2	3	4	5	6	7	8	9	Proportional Parts.								
											1	2	3	4	5	6	7	8	9
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7704	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6

LOGARITHMS.

											Proportional Parts.								
Nat. numb.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	8170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

ANTI-LOGARITHMS.

Log.	0	1	2	3	4	5	6	7	8	9	Proportional Parts.								
											1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1886	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1973	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4

ANTI-LOGARITHMS.

Log.	0	1	2	3	4	5	6	7	8	9	Proportional Parts. 1	2	3	4	5	6	7	8	9
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3753	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8

ANTI-LOGARITHMS.

Log.	0	1	2	3	4	5	6	7	8	9	Proportional Parts. 1	2	3	4	5	6	7	8	9
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16

ANTI-LOGARITHMS.

Log.	0	1	2	3	4	5	6	7	8	9	Proportional Parts.								
											1	2	3	4	5	6	7	8	9
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9338	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

A KEY

TO THE SERIES OF

CHEMICAL PROBLEMS

KEY TO CHEMICAL PROBLEMS.

METRIC SYSTEM OF WEIGHTS AND MEASURES.

1. 43·7 millimetres : 4·37 centimetres.

2. 109876542·1 centimetres : 10987654·21 decimetres : 1098765·421 metres.

3. 70 square decimetres : 7,000 square centimetres : 700,000 square millimetres.

4. The weight of a cubic centimetre of pure water weighed at 4° C. in the latitude of Paris, is styled a gram. A litre denotes a volume equivalent to 1 cubic decimetre. 1,725 grams.

5. 256,700 centigrams.

6. 5,000 milligrams.

7. 78·54 square centimetres.

8. 1·60931 kilometres.

9. 761·985 millimetres.

10. 567·875 cubic centimetres.

11. 113·097 cubic centimetres.

12. 12,732,394 metres.

13. 14·826 millimetres.

14. 7 pieces and 0·023 gram will remain.

15. (*a*) 0·00083 gram, (*b*) 0·00148 gram, (*c*) 0·00231 gram, (*d*) 0·00333 gram, (*e*) 0·00593 gram, (*f*) 0·00926 gram.

16. 3·76 millimetres.

17. 8·305 centimetres.

18. 1·4 millimetres. 0·25 gram.

19. 1·11 cubic centimetres.

20. 50·10 cubic centimetres.

21. − 0·03 c.c., + 0·20 c.c., + 0·41 c.c.

CONVERSION OF THERMOMETRIC SCALES.

22.	15°·5 C.	0°·0 C.	− 12°·5 C.
	100°·0 C.	−26°·38 C.	31°·87 C.
	17°·7 C.	260°·0 C.	− 17°·6 C.
23.	12°·5 R.	519°·1 R.	0°·20 R.
	12°·44 R.	− 32°·0 R.	−14°·22 R.
	0°·0 R.	192°·0 R.	− 7°·55 R.
24.	39°·2 F.	59°·0 F.	413°·6 F.
	59°·9 F.	32°·18 F.	842°·0 F.
	140°·0 F.	212°·0 F.	33°·8 F.

25. 59°·28 C.

26. 94°·82 F., 173°·12 F., 640°·4 F.

27. −31°·04 R., −37·84° F.; 285°·8 R., 675°·05 F.

28. 2822° F., 793°·4 F. 633°·2 F., 455° F.

29. −40°., −32° R.

CORRECTION OF THERMOMETER READINGS.

30. 57·4°.

31. (*a*) 150°·76 to 151°·56, (*b*) 151°·56 to 152°·17, (*c*) 152°·17 to 152°·38, (*d*) 152°·38 to 152°·78.

32. 131°·54 to 131°·64; 131°·64 to 131°·74.

33. 21°·78, 58°·11, 76°·22, 107°·32, 127°·37.

CORRECTION OF BAROMETER READINGS.

34. 752·82 mm., 754·20 mm., 755·38 mm., 756·25 mm.

35. 753·29 mm., 752·69 mm., 750·57 mm., 749·97 mm.

36. *A.* 752·63 mm.
B. 760·72 mm.
C. 755·58 mm.
D. 761·75 mm.
E. 755·49 mm.
F. 758·87 mm.
G. 762·30 mm.

CORRECTION OF THE VOLUMES OF GASES FOR TEMPERATURE AND PRESSURE; LAW OF PARTIAL PRESSURES.

37. 163·992 volumes.

38. 1·3663 litres.

39. 13·3746 litres.

40. (*a*) 1585·165 cubic centimetres, (*b*) 1774·725 cubic centimetres, (*c*) 2049·45 cubic centimetres, (*d*) 3148·35 cubic centimetres. − 91° C.

41. 0·002036 for 1° F., 0·004581 for 1° R

42. From 760 mm. to 767·77 mm.

43. 1743·4 cubic metres.

44. 143·518 c.c.

45. 3677° C.

46. The volume reduced to 0° C. and 760 mm. of the added hydrogen will be 24·10 c.c.
The reading of the upper level of Hg = 423·1 mm.

47. 1·68 per cent.

48. 1·66 per cent., and 0·85 per cent.

49. 48·79 c.c.

50. 24·06 c.c.

RELATIVE DENSITY OF SOLIDS, LIQUIDS, AND GASES; VAPOUR DENSITY.

51. 6·503.

52. 19·11.

53. Granite 2·72; marble 2·68; hæmatite 5·07.

54. 0·8793.

55. 0·268 mm.

56. 0·49 mm.

57. 0·0000219 mm.

58. Relative density of alloy is 8·516.

Percentage of copper = 74·7.
” ” tin = 25·3.

59. 3 cubic centimetres.

60. 1·58.

61. Quartz 2·65; heavy-spar 4·48;
calcite 2·72; iron pyrites 5·0.

62. 1·0272.

63. *A.* 1·00585; *B.* 1·841; *C.* 1·920; *D.* 0·792.

64. Sulphuric acid 1·84 ; mercury 13·54.

65. 0·8.

66. Metal 2·7, liquid 1·19.

67. (*a*) 1·26 ; (*b*) 0·915 ; (*c*) 0·87.

68. Glycerine 1·26 ; mercury 13·598.

69. 0·97176.

70. 0·06935.

71. 59·56.

72. 1·177 ; 16·99.

73. (Air = 1). 1·773 ; 1·712 ; 1·578 ; 1·377 ;
1·321 ; 1·270 ; 1·115 ; 1·021.
(H = 1). 25·59 ; 24·71 ; 22·77 ; 19·87 ;
19·06 ; 18·33 ; 16·10 ; 14·73.

74. 47·29.

75. (1). 0·0792 ; 1·1205 ; 1·5292.
(2). 0·0770 ; 1·1199 ; 1·5414.

76.

	I.	II.	III.
(*A*).	7·67	7·71.	7·69.
(*B*).	110·7	111·29.	111·0.

77. (*A*). 49·60 ; (*B*). 44·70 ; (*C*). 36·07 ;
(*D*). 34·95 ; (*E*). 35·54.

78. 50·29. 4·494 grams.

79. I. 5·75 ; II. 5·74.

80. (Air = 1). *A*. 4·036 ; *B*. 2·621 ; *C*. 0·6012 ; *D*. 8·665.
(H = 1). *A*. 58·26 ; *B*. 37·83 ; *C*. 8·678 ; *D*. 125·1

81. 347·96 kilos.

82. 51·77.

83. 76·33.

84. I. 2·21 ; II. 2·30 ; III. 2·20.

85. 137·7 (H = 1).

DENSITY AND MOLECULAR WEIGHT; VALENCY, EQUIVALENTS, AND ATOMIC WEIGHTS.

86. SH_2, 34·38; NH_3, 17·23; N_2O, 43·88; CH_4, 16·02; $CHCl_3$, 121·25; $SnCl_4$, 265·6.

87.	Oxygen	1·4297	gram.
	Chlorine	3·1666	,,
	Iodine	11·3355	,,
	Sulphur	2·8648	,,
	Phosphorus	5·546	,,
	Nitrogen	1·255	,,
	Sodium	2·0598	,,
	Arsenic	13·419	,,
	Mercury	8·949	,,

88.	Carbon monoxide	799·3	litres.
	Hydrogen sulphide	657·0	,,
	Marsh gas	1397·7	,,
	Water	1243·1	,,
	Ethylene	799·1	,,
	Carbon oxysulphide	372·6	,,
	Bromine	139·9	,,
	Hydrochloric acid	613·8	,,

89. $PbCl_2$, 277·13 gm; $Si F_4$, 104·24 gm;
$Fe Cl_3$, 161·99 ,, ; CH_3Br, 94·73 ,, .

90. CO, 0·967; CS_2, 2·630; SO_3, 2·766; BF_3, 2·358;
PF_5, 4·373.

91. O, 15·96; Ag, 107·66; Cl, 35·37; Sb, 119·58;
Cu, 63·18.

92. The most probable value for the atomic weight of oxygen is 15·96, for this number represents the smallest quantity by weight of oxygen occurring in the molecular weight of any of the given compounds.

93. The approximate molecular weights, calculated from the relative density in each case, are:—16·0; 141·0; 121·3; 27·96; 76·4,—hence the parts given in the third column

refer to parts by weight per molecule and therefore the atomic weight of carbon is 11·97.

94. Cd, 113·7 ; P, 125·6 ; Hg, 201·5.

95. Atomic weight of phosphorus 30·96. From molecular weight found above, molecule is P_4.

DEDUCTION OF EMPIRICAL FORMULA FROM PERCENTAGE COMPOSITION, FORMULÆ OF MINERALS.

96. H_2O_2. 97. NO_2. 98. Fe_2O_3. 99. COS.
100. $KHSO_4$. 101. $MgSO_4 + 7H_2O$.
102. $ZnSO_4 + 7H_2O$. 103. $Ca_3P_2O_8$. 104. Na_3AlF_6.
105. KNO_2. 106. $Al_2(SO_4)_3$.
107. $CuCO_3 + Cu\,H_2O_2$. 108. $NiSO_4 2NH_3$.
109. C_nH_{2n}. 110. C_2H_2. 111. $C_2H_6SO_4$. 112. $C_{10}H_{14}N_2$.
113. $(C_{21}H_{22}N_2O_2)_2H_2PtCl_6$.

114. A comparison of the amount of oxygen contained in the various bases with that contained in the acid, shows that the two quantities are in the ratio of 1 : 2, in conformity with the formula $MOCO_2$ thus—

		Containing oxygen.		*Ratio.*
CaO	28·4	8·11	16·19	1
MgO	12·3	4·92		
FeO	12·3	2·73		
MnO	1·9	0·43		
CO_2	44·4		32·3	2
	99·3			

115. $2(MgO\ SiO_2) + 3H_2O$.

116. $Co_3As_2O_8 + 8H_2O$.

117. $Na_2O\ Al_2O_3\ 6SiO_2$.

118. $3CaO, Na_2O, 4Al_2O_3, 12SiO_2$.

TO CALCULATE THE PERCENTAGE COMPOSITION OF A COMPOUND FROM ITS FORMULA.

119.	Hydrogen	11·14
	Oxygen	88·86
		100·00

120.	Potassium	31·92
	Chlorine	28·93
	Oxygen	39·15
		100·00

121.	Mercury	92·57
	Oxygen	7·43
		100·00

122.	Potassium	38·67
	Nitrogen	13·88
	Oxygen	47·45
		100·00

123.	Sodium	27·09
	Nitrogen	16·50
	Oxygen	56·41
		100·00

124.	Barium	58·82
	Sulphur	13·74
	Oxygen	27·44
		100·00

125.	Calcium	40·00
	Carbon	12·01
	Oxygen	47·99
		100·00

126.	Silver	75·27
	Chlorine	24·73
		100·00

127.	Magnesium	21·61
	Phosphorus	27·95
	Oxygen	50·44
		100·00

128.	Potassium	16·11
	Platinum	40·10
	Chlorine	43·79
		100·00

129.	Sodium	18·57
	Sulphur	25·83
	Oxygen	19·33
	Water	36·27
		100·00

Or—	Sodium	18·57
	Sulphur	25·83
	Hydrogen	4·04
	Oxygen	51·56
		100·00

130.	Iron	72·42
	Oxygen . . .	27·58
		100·00

131.	Manganese. .	72·03
	Oxygen . . .	27·97
		100·00

132.	Copper . . .	34·52
	Iron	30·53
	Sulphur. . .	34·95
		100·00

133.	Silver . . .	53·07
	Copper . . .	31·15
	Sulphur. . .	15·88
		100·00

134.	Lime (CaO) .	9·20
	Alumina (Al_2O_3)	16·79
	Silica (SiO_2) .	59·21
	Water . . .	14·80
		100·00

135.	Lime. . . .	43·49
	Alumina. . .	17·64
	Silica. . . .	38·87
		100·00

136.	Lithia . . .	6·44
	Alumina. . .	29·21
	Silica. . . .	64·35
		100·00

137.	Lime. . . .	44·42
	Silicon dioxide	23·82
	Titanium „	31·76
		100·00

138.	Lead. . . .	76·34
	Phosphorus .	6·87
	Chlorine. . .	2·62
	Oxygen . . .	14·17
		100·00

139.	Carbon . . .	52·16
	Hydrogen . .	13·07
	Oxygen. . .	34·77
		100·00

140.	Carbon . . .	42·10
	Hydrogen . .	6·45
	Oxygen . . .	51·45
		100·00

141.	Carbon . . .	90·54
	Hydrogen . .	9·46
		100·00

142.	Carbon	89·53
	Hydrogen	10·47
		100·00

143.	Silicon	19·48
	Carbon	66·61
	Hydrogen	13·91
		100·00

144.	Carbon	21·02
	Hydrogen	2·63
	Potassium	34·26
	Oxygen	14·01
	Sulphur	28·08
		100·00

145.	Potassium	42·44
	Iron	15·19
	Carbon	19·52
	Nitrogen	22·85
		100·00

146.	Carbon	32·18
	Hydrogen	6·05
	Nitrogen	28·25
	Oxygen	21·45
	Water	12·07
		100·00

147.	Carbon	75·19
	Hydrogen	6·60
	Nitrogen	13·20
	Oxygen	5·01
		100·00

148.	Carbon	75·41
	Hydrogen	6·60
	Nitrogen	8·42
	Oxygen	9·57
		100·00

CALCULATIONS OF THE AMOUNT OF MATERIAL REQUIRED TO PRODUCE A GIVEN WEIGHT OF ANY SUBSTANCE, OR OF THE QUANTITY OF THE SUBSTANCE PRODUCED BY THE DECOMPOSITION OF A KNOWN WEIGHT OF MATERIAL.

149. 2·554 lbs.

150. (*a*) 27·038 kilos., (*b*) 5·1088 kilos., (*c*) 16·307 kilos., (*d*) 12·208 kilos.

151. 33·275 grams; 13·029 grams.

152. 709·84 grams.

153. 4306·0856 kilos. zinc; 6492·3134 kilos. H_2SO_4.

154. 3708·8 kilos. iron; 4306·1 kilos. zinc; 32461·5 kilos. sulphuric acid.

155. 177·256 grams.

156. 12,939·8 c.c. hydrogen; 6469·9 c.c. oxygen.

157. 322·216 grams Fe_3O_4; 132·029 litres of hydrogen.

158. 0·91048 lbs. copper; 0·1784 lbs. phosphorus.

159. 6·096 grams ammonia; 9·506 grams chlorine.

160. 140·1 kilos. KNO_3; 117·8 kilos. $NaNO_3$.

161. 10·116 lbs. nitre; 9·805 lbs. sulphuric acid.

162. 9·08 litres.

163. 4·246 grams.

164. 5·477 kilos. lime; 10·446 kilos. sal-ammoniac.

165. 183·03 kilos. of coal.

166. Assuming air to contain 23 per cent. by weight of oxygen, 11·94 tons.

167. 42·36 grams marble; 140·42 grams hydrochloric acid solution.

168. 146·215 tons carbon; 3275 cubic feet.

169. (1) 130·53 litres; (2) 130·53 litres.

170. 40·223 grams oxalic acid; 20·559 grams formic acid; 27·444 grams potassium ferrocyanide.

171. 36·67 grams sodium acetate.

172. 707·333 kilograms.

173. 76·395 kilos. air; 10·73 kilos. water;
12·353 kilos carbon dioxide.

174. 106·99 grams silver chloride; the solution will contain 17·79 per cent. of hydrocyanic acid.

175. 43·647 grams.

176. 16·501 tons of salt; 20·778 tons of manganese dioxide; 47·683 tons of sulphuric acid.

177. 51·294 tons of hydrochloric acid;
2,558,701 litres will escape.

178. 1·7355 grams precipitated; 1·907 grams in solution.

179. 192·33 tons of $\{Ca(OCl)(OH)\}_2, CaCl_2$.

180. According to the equation

$$3Cl_2 + 6KOH = KClO_3 + 5KCl + 3H_2O,$$

28·201 tons of $KClO_3$.

181. 181·10 grams.

182. 72·135 grams iodine; 100·815 grams chlorine.

183. 8·49 grams copper; 26·29 grams sulphuric acid.

184. 54·487 tons of pyrites; if 3 per cent. of the theoretical yield of sulphur remained unburnt, 97 tons of the dilute acid would be produced.

185. 224·28 litres.

186. 3·935 grams ferrous sulphide; 9·325 grams air.

187. 1·802 litres.

188. 2·0488 grams microcosmic salt.

189. 82·19 tons of sulphur; 68 tons of salt cake; 107·742 tons of bicarbonate; 183·398 tons of soda crystals; 56·87 tons of solid caustic.

190. 17·474 tons of limestone.

191. 138·14 grams Fe_3O_4; 289·889 grams Fe_2Cl_6.

COMBINATION AND DECOMPOSITION OF GASEOUS BODIES.

192. 20 litres of hydrochloric acid gas; 10 litres of hydrogen remain in excess.

193. 1 cubic foot of hydrobromic acid gas.

194. 50 vols. of chlorine; 25 vols. of oxygen.

195. 154·97 c.c.

196. 3 litres of oxygen.

197. 110·34 c.c.

198. 500 c.c. nitrogen; 1500 c.c. hydrogen.

199. V. 1·25. n vols. oxygen; V.n vols. carbon dioxide.

200. (1) 95·42 litres; (2) 143·13 litres; (3) 119·27 litres,

201. 5 litres phosgene gas; 5 litres carbon dioxide, weighing 9·8296 grams, and 10 litres hydrochloric acid gas, weighing 16·2903 grams.

202. 1 litre, on the assumption that its density is normal.

GAS ANALYSIS CALCULATIONS.

203. N, 79·060 per cent.; O, 20·940 per cent.

204. N, 83·37 per cent.; O, 13·80 per cent.; CO_2, 2·83 per cent.

205. 3·48 per cent. of aqueous vapour.

206. 26·46 vols. of oxygen unite with 52·71 vols. of hydrogen.

207. C (hypothetical vapour volume), 1·025; H, 3·129; O, 0·484.
The empirical formula of methyl ether is C_2H_6O.

208. N_2O.

209. N, 81·81 per cent.; O, 14·21 per cent.;
CO_2, 2·44 per cent.; SO_2, 1·54 per cent.;
H, 45·07 per cent.; SH_2, 24·25 per cent.

210. CO_2, 29·96 per cent.; N, 0·72 per cent.;
CO & CH_4, none.

211. The percentages of N are:—*A*, 7·39; *B*, 16·28; *C*, 16·16; *D*, 15·00; *E*, 13·99; *F*, 4·48.
The volumes of gases obtained, reduced to 0° C. & 760 mm. are:—

	A.	B.	C.	D.	E.	F.
N.	7·21 c.c.	10·34 c.c.	10·07 c.c.	9·96 c.c.	9·66 c.c.	4·48 c.c.
NO.	0·47 ,,	0·91 ,,	1·16 ,,	0·55 ,,	0·25 ,,	0·03 ,,

212. Total oxygen added = 239·3, of which 236·98 is used. Carbon dioxide formed = 118·8 = oxygen used in burning C. Hence O used to burn H = 118·18.
∴ Vol. of H would be 236·36 and hypothetical vol. of C. $\frac{118·8}{2} = 59·4$.
Hence composition of marsh gas is represented by CH_4.

213. 0·53 per cent. by volume.

214. 0·47 per cent. by volume.

215. The percentage composition of this sample of coal-gas is :—

CO_2. 1·41 ; CO. 6·15 ;
C_2H_4 &c. 3·84 ; H. 47·73 ;
C_6H_6. 1·04 ; CH_4. 35·63 ;
O. 0·30 ; N. 3·90.

216. 3 vols. ethylene ; 1·98 vols. butylene. Equal in illuminating power to a gas containing 6·96 per cent. of ethylene.

ATOMIC WEIGHT DETERMINATIONS.

217. 1·00108.

218. From synthesis of silver nitrate 13·967
By precipitation with potassium chloride 14·026
By precipitation with ammonium chloride 13·945
Mean 13·979

219. 35·356.

220. 39·033.

221. 199·6.

222. (1) 12·014, (2) 12·014, (3) 12·030. Mean = 12·019.

223. 27·029.

224. 27·028.

225. 27·012.

226. 48·06 ; 48·07 ; 47·98 ; 48·04 ; 48·04.

227. 196·88 ; 196·90 ; 196·86 : 196·85 ;
196·89 ; 196·86 ; 196·85 ; 196·89.

228. 28·347 ; 28·303 ; 28·347 ; 28·352 ; 28·243.

229. 52·061.

230. 65·506.

INDIRECT ANALYSIS.

231. 33·51.

232. 93·03.

233. 39·98.

234. 11·61.

235. 25·51.

236. 58·035 grams.

237. K, 13·75 per cent.; Na, 8·25 per cent.

238. 0·6281 gram NaCl; and 0·3049 gram Na I.

GENERAL ANALYTICAL QUESTIONS.

239. (*a*) 0·1998 gram of the salt gave 0·4865 gram silver chloride, and 0·0032 reduced silver.

$$0·0032 \text{ gm. Ag} = 0·00425 \text{ Ag Cl};$$

$$0·4865 + 0·00425 = 0·49075 \text{ gm. Ag Cl};$$

$$\frac{0·49075 \times 35·37 \times 100}{143·03 \times 0·1998} = 60·74 \text{ per cent. chlorine.}$$

(*b*) 0·9543 gram of the salt gave 1·1584 gram sodium sulphate.

$$\frac{1·1584 \times 45·99}{141·81} = 0·37568;$$

$$\text{and } \frac{0·37568 \times 100}{0·9543} = 39·36 \text{ per cent. sodium.}$$

$\frac{60·74}{35·37} = 1·7$; $\frac{39·36}{23} = 1·7$; hence the chlorine and sodium in the compound are in the ratio of atom to atom, and the formula of the salt is Na Cl.

240. 0·3951 gram of substance gave 0·6544 gram of NH_4MgAsO_4, H_2O = 0·3781 gram As_2O_5: hence the substance contained 95·70 per cent. arsenic anhydride.

241. The percentage results of the analysis are :—

Silica	40·35
Ferric oxide	36·43
Water	20·62
Lime	2·68
	100·08

Neglecting the lime as an unessential constituent, the percentage composition of the mineral becomes :—

Silica	41·46
Ferric oxide	37·43
Water	21·19
	100·08

The simplest ratios of the oxygen contained in each of the constituents is 6 : 3 : 5. Hence the formula of the compound is 3 SiO_2, F_2O_3, 5 H_2O.

242. 164·1 grams of K_2PtCl_6 are equivalent to 50·39 grams of potassium chloride. Hence the composition of the mixture is :—

Potassium chloride	50·39
Sodium chloride	49·61
	100·00

243. 0·2476 gram Tl_2PtCl_6 = 0·1239 grams thallium, or 67·67 per cent. Its composition is therefore :—

Tl.	67·67
ClO_4.	32·33
	100·00

$$\frac{67{\cdot}67}{203{\cdot}7} = 0{\cdot}332. \quad \frac{32{\cdot}33}{99{\cdot}21} = 0{\cdot}325.$$

Hence the formula is $Tl\,Cl\,O_4$.

244. Centesimal hydrochloric acid corresponds to 1·0766 grams of Ag per litre, hence Ag used = 7·383 − 0·0032298 grams = 7·37977 grams; and $\dfrac{7{\cdot}37977 \times 35{\cdot}37 \times 100}{107{\cdot}66 \times 3{\cdot}949}$ = 61·40 per cent. chlorine.

245. $2\,BaSO_4 = O$. $AgBr = Br$.

0·402 gram $BaSO_4$ = 0·01378 O.
0·324 gram $Ag\,Br$ = 0·1372 Br.

$$\frac{0{\cdot}01378}{15{\cdot}96} = 0{\cdot}00086. \quad \frac{0{\cdot}1372}{79{\cdot}76} = 0{\cdot}00172.$$

Hence the formula is $Br_2\,O$.

246. $KClO_4 = HClO_4$. 1·6785 $KClO_4$ = 1·2167 $HClO_4$ or 99·85 per cent. $HClO_4$.

0·966 gm. lost 0·444 gm. O, or 45·97 per cent.: $KClO_4$ ought to lose 46·18 per cent.

0·966 − 0·444 = 0·522 KCl; this required 0·744 gram of silver for precipitation: theory requires 0·7523 gram.

247. $Na\,H\,CO_3 + CH_3\,.\,COOH = CH_3\,.\,COONa + CO_2 + H_2\,O$ or 43·89 parts of CO_2 = 59·86 parts of $CH_3\,.\,COOH$. Then 0·427 CO_2 = 0·5823 $CH_3\,.\,COOH$,

$$\text{and } \frac{0{\cdot}5823 \times 100}{1{\cdot}483} = 39{\cdot}26 \text{ per cent.}$$

248. $NaOH = HCOOH$. Then 1·01558 NaOH = 1·1664 HCOOH and $\dfrac{1{\cdot}1664 \times 100}{2{\cdot}122}$ = 54·967 per cent.

249. 2·921 vols. CO_2, in 10,000 vols. of air.

250.

Sodium chloride	26·402.
Potassium chloride	0·7459.
Magnesium chloride	3·0368.
Magnesium bromide	0·0705.
Magnesium sulphate	2·0648.
Calcium sulphate	1·2896.
Calcium carbonate	0·0475.
Ammonium chloride	0·00035.
Magnesium nitrate	0·00185.
Ferrous carbonate	0·00674.
MgO unaccounted for	0·02904.

251. 22·53 candle power.

252. (1) $C_6\,H_4\,Br\,C_2H_5 + Na_2 + CO_2$
$= C_6\,H_4\,C_2\,H_5\,COO\,Na + NaBr.$

(2) $C_6\,H_4\,C_2\,H_5\,COO\,Na + HCl$
$= C_6\,H_4\,C_2\,H_5\,COOH + NaCl.$

and the acid gave on treating with baryta water the barium compound, of which 0·5637 gram lost 0·0430 gram water, or 7·63 per cent.; and gave 0·2733 gram barium sulphate, or 28·517 per cent. Ba. Hence the composition of the salt is:—

$C_9H_9O_2$	63·85
Ba	28·52
$H_2\,O$	7·63
	100·00

$$\frac{63{\cdot}85}{148{\cdot}65} = 0{\cdot}429\,; \quad \frac{28{\cdot}52}{136{\cdot}86} = 0{\cdot}209\,; \quad \frac{7{\cdot}63}{17{\cdot}96} = 0{\cdot}425.$$

Hence formula is $Ba\,(C_9\,H_9\,O_2)_2$, $2\,H_2\,O$.

253. 1·994 per cent. nitrogen.

254. The composition of the body, as determined by experiment, is:—

Carbon	36·43
Hydrogen	7·91
Chlorine	55·66

The simplest relation between these numbers is represented by $C_2 H_5 Cl$, which formula requires :—

Carbon	37·22
Hydrogen	7·77
Chlorine.	55·01

The vapour density found is 32·44, calculated 32·15.

255. Na Cl. 66·39 per cent.
KCl. 33·61 per cent.

256. NaCl. 60·3 per cent.
NaBr. 39·7 per cent.

SOLUTION OF GASES.

257. 20 c.c.; 14·96 c.c.; 7·82 c.c.; 0·286 c.c.

258. The volume is the same in each case, 15·90 c.c. The weights are respectively :—

0·025124 gram ; 0·018792 gram ;
0·0098237 gram ; 0·0003593 gram.

259.	(*A*)	(*B*)	(*C*)
(*a*)	6·664 c.c. ;	6·553 c.c. ;	6·454 c.c.
(*b*)	6·344 c.c. ;	6·291 c.c. ;	5·832 c.c.

260. 1·4584 ; 1·2607 ; 1·0385 ;
0·9610 ; 0·9134 ; 0·8852.

261. 0·06910 ; 0·06853 ; 0·06769 ; 0·06732 ; 0·06669.
Water : 0·02134 ; 0·02099 ; 0·01956 ; 0·01912 ; 0·01839.

262. $0·032874 - 0·00081632\, t + 0·000016421\, t^2$.

263. 39·36 per cent. O. and 60·64 per cent. N.

264. By volume :—44·7 per cent. CO_2 ;
55·3 per cent. N.

265. 92·07 per cent. H. ;
7·93 per cent. CO_2.

MOLECULAR WEIGHT AND LOWERING OF THE FREEZING-POINT.

266. 15·34° C.

267. 73·44.

268. 0·5256°.

269. 1·69 per cent.

270. 2·867°; 2·488°; 1·482°.

271. (1) 72·58; (2) 73·50; (3) 71·97; (4) 73·60.

272. (*a*) 111·87; (*b*) for Na, 14·49; (*c*) for Sn, 73·93.

273. $MgSO_4, 7\ H_2O$.

274. $L = \frac{0·02.\ (280·9)^2}{117·9} = 13·38.$

275. $\frac{18·5}{·63} = 29$; $\frac{27·7}{·63} = 44$; $\frac{38·6}{·63} = 61$; the numbers here obtained according to Raoult should represent the molecular weight of the solvent in each case; in the cases of formic and acetic acids this holds very nearly but in the case of water 29 bears no simple relation to 18 the molecular weight of water in the gaseous state, the conclusion may therefore be drawn that the molecule of water in the liquid state is more complex than the molecules of formic and acetic acids under similar conditions.

276. From (*a*) the molecular weight deduced is 65·80, from (*b*) 65·99; for $N_2\ O_4$ molecular weight is 92, for NO_2 it is 46; hence it is probable that at the temperature of the experiment nitrogen tetroxide consists of a mixture of N_2O_4 and NO_2.

277. (*a*) 196·2; (*b*) 196·5.

SPECIFIC HEAT, LATENT HEAT, AND ATOMIC HEAT.

279. 18° C.

280. 0·0327.

281. 0·03308.

282. 0·0335.

283. 0·208.

284. 3°·08.

285. 893° C.

286. 0·1137.

287. 774·6 for 1° F.

288. 33681 metres.

289. Sp. Ht. of Indium is 0·0574.

290. (*A*) 0·0559 ; (*B*) 0·0935 ; (*C*) 0·0495 ; (*D*) 0·0548 ; (*E*) 0·1712.

291. 28·4° C.

292. 7·284 kilos. per hour.

293. 537·2.

294. Pb 6·48 ; Ag 6·13 ; Cu 6·01 ;
Fe 6·36 ; S 6·48 ; P 5·84.

295. Approximate atomic weights :—Ag, 112·3 ;
Zn, 66·98 ; Bi, 207·5 ; Sn, 113·8 ; Fe, 56·23.
Exact atomic weights :—Ag, 107·66.
Zn 64·88 ; Bi, 207·5 ; Sn, 117·35 ; Fe, 55·88.

296. 5·67 = atomic heat of solid chlorine.
2·98 and 3·06 are the atomic heats for O calculated from the respective oxides.

297. 3·8.

298. 2.

299. Ca 5·6 ; Sr, 6·3 ; Ba 6·4.

HEAT OF SOLUTION AND COMBINATION.

300. 34·462 kilos.

301. 5·747° C.

302. 0·148 kilos.

303. (1) ethylene 2714·5°; (2) methane 2381·3°.

304. 2677·6°.

305. 7,614 thermal units.

306. 8095·6.

307. 3386·4 metres.

308. 192,700 +.

309. 20,200 +.

310. 28,400 −.

311. 18,500 −.

312. 13,080 −.

313. (*a*) 55,100 +; 45,200 −.

314. 5,590 −.

315. 21,150 +.

316. It may be concluded that $H_3 PO_3$ is a dibasic acid, for the addition of sodic hydrate beyond two equivalents causes but a very slight liberation of heat, and from nothing to two equivalents the heat evolved is considerable and proportional (or nearly so) to the amount of sodic hydrate added.

THE END.

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